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ORIGINAL ARTICLES.

Metasomatism in the Whin Sill of the North of England. Part I: Metasomatism by Lead Vein Solutions.

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(PLATE XI.)

GENERAL INTRODUCTION.

THE products of the metasomatism of igneous rocks are found for the most part only in small quantities since diffusion through a solid rock of the solutions responsible for metasomatic changes is a slow process. In the Whin Sill there are two types of metasomatic alteration product which though insignificant in total amount are nevertheless widely distributed. The first type, which was formed along the walls of an early joint system by the action of juvenile solutions, is part of the history of the cooling down of the Whin Sill and will be described in a subsequent paper. The second type was produced by the action of lead vein solutions. Although unconnected with any stage in the cooling down of the Whin Sill, this type has an important bearing on the general mechanism of replacement and especially on the part played by diffusion, whose effects may be seen in both types as an extended transition between altered and unaltered dolerite.

THE OCCURRENCE AND FIELD RELATIONS OF WHITE WHIN.

For a variable distance, from a few inches to several feet, from the lead veins which cut the Carboniferous rocks and the intruded Whin Sill in the Teesdale and Alston Moor mining districts, the Whin Sill has been altered to a whitish, hard and compact rock closely resembling the white traps of the Midland Valley of Scotland (Flett, 1910, p. 311). The miners of the district call this type of altered Whin Sill *burnt* or *white whin*, and since there is as yet no concise scientific name for this type of alteration product, the term white whin will be used. As most of the mines have closed down, and as the Whin Sill level was rarely very productive, it is now becoming difficult to find accessible places where lead veins can be seen cutting through the Whin Sill. White whin has been found at the following localities :—

(1) Rotherhope Fell Mine, near Alston (Smith, 1923, pp. 96–9). The Whin Sill is here not exposed at the surface and work in the mine is now at a higher level than the Whin Sill, so that only large blocks on the old dumps could be examined.

(2) Adjacent to a barytes vein exposed in the left bank of the stream running down from Green Castles, near the head of Knock Ore Gill, Westmorland. The barytes vein is 4 feet wide, and alteration to white whin extends for several feet on both sides of the vein.

(3) Park End Quarry, 1½ miles East of Middleton-in-Teesdale. A small mineral vein carrying galena and barytes cuts through the quarry in a north-east direction, and though being fast removed by quarrying, was well exposed in the summer of 1927. The cleft up which the lead vein solutions passed is in places without ores, but whether marked by ores or not, the dolerite is altered to white whin for a distance of 6 to 12 inches from the cleft. This type of alteration was found nowhere else in the quarry, neither along other important joint planes nor at the contact of the dolerite and the sediments.

(4) In the exposures of Whin Sill forming the bed of the Tees between Scawberry Bridge and Winch Bridge near Holwick in Upper Teesdale. At this locality the white whin occurs in irregular patches quite free from the usual minerals of the lead veins, but cut by abundant narrow chalybite veins. White whin was first found at this locality, and it was for some time suspected to be white trap, formed as the white traps in the Midland Valley of Scotland by the action of organic gases distilled from adjacent carbonaceous sediments. No relation could be established between the occurrence of white whin and the character of the invaded sediments; since its occurrence was not sufficiently uniformly widespread in exposures of the Whin Sill, it could not be due to weathering, or the effect of late-stage solutions of the dolerite itself. Ultimately similar material was found adjacent to lead veins, and it is considered that the white whin of this locality has been produced by lead vein solutions, which, though not leaving direct evidence of their presence by the deposition of lead vein minerals, nevertheless penetrated the dolerite extensively.

(5) On the south bank of the Tees, 30 yards upstream of Winch Bridge, near Holwick. This is a dyke-like mass more regular than the occurrences downstream of Winch Bridge, and the altered dolerite is 20 to 30 feet within the Whin Sill, whereas the exposures downstream of Winch Bridge (locality 4) are usually nearer the upper surface of the sill. Lead vein minerals are absent but again chalybite and other carbonates occur in small veins in the white whin.

(6) Ord and Maddison's Quarry, Middleton-in-Teesdale Station. The white whin occurs here in a rib of somewhat shattered dolerite which divides the old quarry from the new. No lead vein minerals were found, but small veins of chalybite and other carbonates were abundant in the white whin and absent in adjacent unaltered dolerite.

Other occurrences with or without lead vein minerals have been found in Teesdale and Weardale, but they do not require special description.

PETROGRAPHY.

Under the microscope the mineralogical composition of the white whin from the localities listed above, with the exception of that from Rotherhope Fell Mine (locality 1), is found to be qualitatively very similar. The chief constituents are quartz, carbonates, micaceous minerals, anatase and apatite. By comparison with the sub-ophitic texture of unaltered Whin Sill (Pl. XI, Fig. 1) the *micaceous minerals*, occurring as minute crystals irregularly arranged within lath-shaped areas, are seen to replace the lath-shaped felspars of the unaltered dolerite, and the carbonates are seen to replace with greater or less exactness the ferromagnesian minerals (Pl. XI, Fig. 2). The most altered rock, which forms the greater part of the white whin at Winch Bridge (locality 5) and which has been analysed (A, Table I), will be chosen for detailed description. The ndividual crystals of the micaceous material replacing the felspars have a length and breadth of about 0·007 mm., so that there are several in the thickness of a slice. Under crossed nicols the areas of micaceous material have a general speckled appearance in first order greys, but even in the larger flakes, which show first order yellows or reds in a slice of normal thickness, it is impossible to make any adequate determination of optical properties. An analysis of he rock (A, Table I) shows that there is 1·03 per cent of Na_2O and ·60 per cent of K_2O, and, as no albite or other definite soda mineral an be seen in the slice, both soda and potash have been tentatively onsidered to be present in a hypothetical muscovite-paragonite molecule. With this assumption the mica is found to consist of about qual weights of muscovite and paragonite (see Table II). Only oubtful analyses of micas of this sort of composition seem to be ecorded, but F. L. Ransome (1911, p. 99) in a somewhat similar ock has assumed without comment that potash and soda are present n a mica of very much this composition. Sufficient alumina remains fter an appropriate amount has been allotted to the potash and oda to give 19·6 per cent of kaolin. Careful examination of the areas f micaceous material under high powers has shown that some of he larger crystals give first-order red interference colours; these re probably mica. Other equally large crystals give low grey nterference colours and since such crystals occur too frequently or them to be explained as basal sections of the rare, relatively large mica crystals, they are believed to represent some of the kaolin whose presence may be deduced from the analysis. In sections of white whin from Knock Ore Gill (locality 2) the kaolin occurs in crystals often ·02–·04 mm. in length and breadth, and its almost straight extinction, positive elongation and low double refraction can be determined. A colourless micaceous mineral with a birefringence of ·01 ± ·001 which is too low for muscovite and too high for kaolin, also occurs not infrequently in moderate sized flakes. The central part of the felspars in material from Ord and Maddisons quarry (locality 6) is replaced by micaceous minerals closely resembling those in the Winch Bridge rock, but the outer margins are frequently of material which, although of much the same refractive index, is almost isotropic and is regarded as kaolin in very minute crystals.

In the Winch Bridge rock *carbonate* occurs in two different ways. The greater part forms patches, cloudy with minute inclusions and having the shape of the original pyroxene areas. The inclusions are very minute, but seen with a $\frac{1}{12}$ in. objective, they resemble both in colour and form minute clusters of anatase. Teall (1884, p. 148) in his analysis of the pyroxene of the Whin Sill at Cauldron Snout apparently did not determine TiO_2, but probably sufficient is present to account for these minute inclusions. Carbonate also occurs as clear isolated patches not having the shape of former ferromagnesian minerals ; as is shown later it is produced by the aggregation of calcite liberated by the decomposition of the plagioclases. From the analysis (A, Table I) it may be calculated that the carbonate consists largely of calcium carbonate with subsidiary magnesium and iron carbonate (cf. Milch, 1903, p. 508). Former ilmenite is represented by groups of isolated *anatase* crystals of tabular habit usually shadowing the shape of the original mineral. In connection with the conditions of temperature under which white whin was formed, it is significant that both petrological and experimental evidence indicates that anatase is the low temperature form of TiO_2. The only other constituents of white whin are *quartz* and *apatite*, which from their situation and form may be seen to be original unaltered minerals of the dolerite.

Frequently the replacing minerals are more scattered about the slice than in the Winch Bridge rock, and it is often difficult to decide by a comparison of the textures of the altered and unaltered dolerite which minerals are replacing each other. With this proviso the description of the Winch Bridge rock is generally applicable to material from all the localities examined, except that from the Rotherhope Fell mine. Material from this locality has been analysed and briefly described by A. M. Finlayson (1910, pp. 304–5). In the most altered material which can now be obtained, shot through by galena and fluorspar veins, a felspar with refractive index lower than balsam was found in considerable abundance. Kaolin was also observed in several sections, and, in the material analysed by Finlayson, its presence may be suspected, since there still remains sufficient alumina to give 5·3 per cent. of kaolin, even if the potash and soda are calculated as muscovite thereby using up more alumina than if some were put into an alkali felspar. Though carbonates are found replacing the pyroxenes in the transition stage between the white whin and the unaltered dolerite from this locality, the most altered rocks consist of irregular muscovite, kaolin, orthoclase, anatase and apatite crystals with abundant quartz and little or

TABLE I.

	A.	B.	C.	D.	E.	F.
SiO_2	35·10	50·80	50·46	62·29	46·06	36·8
Al_2O_3	18·09	14·24	13·89	12·27	15·94	22·95
Fe_2O_3	trace	3·84	3·69	1·29	2·94	—
FeO	3·74	8·90	9·02	8·65	7·44	4·08
MgO	5·79	5·12	5·03	2·45	4·14	2·85
CaO	11·89	8·44	8·81	3·29	7·04	9·73
Na_2O	1·03	2·72	2·85	·23	4·95	·5
K_2O	1·60	1·32	1·33	2·66	2·76	1·1
$H_2O +$	4·18	1·67	1·95	1·65	4·22	7·7
$H_2O -$					·55	
CO_2	16·12	·21	·19	4·34	·11	11·9
TiO_2	2·31	2·20	2·26	1·13	2·56	2·6
P_2O_5	p.n.d.	·21	·37	·32	·84	·75
Cl	n.d.	—	—	—	trace	—
FeS_2	nt. fd.	—	—	—	·36	—
(CoNi)O	n.d.	—	—	—	nt. fd.	—
MnO	p.n.d.	·23	·22	·27	·31	trace
SrO	n.d.	—	—	—	nt. fd.	—
BaO	n.d.	—	—	—	·10	—
Li_2O	n.d.	—	—	—	? trace	—
	99·85	99·90	100·07	100·84	100·32	100·96
S.G.	2·73	2·92	2·85	2·65	—	—

A.—Altered Whin Sill (White Whin), Winch Bridge, Teesdale, Yorkshire. Anal. L. R. Wager.

B.—Average of three analyses of the Whin Sill:—

(*a*) Whin Sill, Cauldron Snout, Durham, J. J. H. Teall, *Quart. Journ. Geol. Soc.*, xl, 1884, p. 654. Anal. J. J. H. Teall.

(*b*) Whin Sill. Crags near Roman station of Bourgovicus, Northumberland. J. J. H. Teall. *Quart. Journ. Geol. Soc.*, xl, 1884, p. 654. Anal. J. J. H. Teall.

(*c*) Whin Sill diabase, fresh. Rotherhope, near Alston, A. M. Finlayson, *Quart. Journ. Geol. Soc.*, lxvi, 1910, p. 304. Anal. A. M. Finlayson.

C.—Whin Sill diabase, fresh, Rotherhope, near Alston. A. M. Finlayson, *Quart. Journ. Geol. Soc.*, lxvi, 1910, p. 304. Anal. A. M. Finlayson.

D.—Whin Sill diabase, altered, Rotherhope, near Alston, A. M. Finlayson. *Quart. Journ. Geol. Soc.*, lxvi, 1910, p. 304. Anal. A. M. Finlayson.

E.—Teschenite, Mons Hill, (shore at Whitehouse Point), Dalmeny, Midlothian. "The Geology of the neighbourhood of Edinburgh," *Mem. Geol. Sur. Scotland*, 1910, p. 312. Anal. E. G. Radley.

F.—White Trap, Newalls, South Queensferry, Mid-Lothian. *Proc. Roy. Soc. Edinb.*, vol. xv, 1888, p. 172. Anal. E. Stecher.

no carbonate. As Finlayson's analysis (cf. columns C and D, Table I) seems to represent an uncertain stage in the transition from unaltered Whin Sill to white whin, and as material cannot now be collected *in situ*, little can be deduced from this unusual case, except that very different alteration products may be formed adjacent to mineral veins which seem in all significant points to be the same. It is interesting in this connection to note that the mineralogical composition of the Winch Bridge white whin is much closer to that of the white trap, formed in a very different way from the Mons Hill teschenite (Flett, J. S., 1910, p. 313), than it is to the white whin adjacent to the Rotherhope Fell lead vein.

Table II.—Calculated Composition of the Altered Whin Sill (White Whin) Calculated from the Analysis A, Table I.

Carbonate	Calcite	21·2	35·8
	Chalybite	6·0	
	Magnesite	8·6	
Mica	Muscovite	13·5	26·7
	Paragonite	13·2	
Kaolin			19·6
Silica			14·0
Anatase			2·3
Apatite			p.n.d.
			98·4

The Interpretation of the Analysis and its bearing on the Composition of the Solutions producing the Metasomatism.

An analysis of the completely altered material from Winch Bridge (locality 5) was made in the Mineralogical Laboratory at Cambridge, by the kind permission of Professor Hutchinson. Several sections of material from this locality have been examined and they show that, though the alteration can be found at various stages, it seems to have proceeded to a definite endpoint, giving the rock whose petrography has already been described in detail. The bulk of the rock at the Winch Bridge exposure, as will be explained later when the transition between altered and unaltered dolerite is described, has apparently reached equilibrium with the active solutions producing the metasomatism; it is this material which was selected for analysis. As the Whin Sill has been shown to be remarkably constant in composition (Holmes and Harwood, 1928), no new analysis has been made of the Whin Sill adjacent to the white whin at Winch Bridge, but for comparison the average of the analyses of the Whin Sill given by Teall (1884, p. 654) and Finlayson (1910, p. 304) has been used.

Every comparison of the analysis of a rock and its metasomatic alteration product with a view to deciding the gains and losses of the various constituents during metasomatism implies some assumption which has not always been clearly stated (cf. Finlayson, 1910, pp. 304–5). Lindgren and others (Lindgren, 1918, Boydell, 1926, p. 24) have assumed as a basis for comparison that in metasomatism the volume of replacing minerals equals the volume of minerals replaced. Such an assumption is considered the more justifiable the more accurately the texture of the original rock is preserved after metasomatism. The ophitic texture of the Whin Sill dolerite, as has already been explained, is well preserved in the white whin (cf. Figs. 1 and 2, Plate XI), and a calculation of the weights in 100 c.c. of altered and unaltered dolerite was made on the assumption of no change in volume during metasomatism. When the modified analyses were compared it was found, however, that alumina has been added to the rock. This was improbable both from the microscopic and field evidence. No aluminium minerals have been seen either n the lead and chalybite veins or in the areas of carbonate after pyroxene. The absence of evidence for the migration of alumina,

TABLE III.

	A.	B.
SiO_2 . . .	27·6	50·8
Al_2O_3 . . .	14·2	14·2
Fe_2O_3 . . .	0·0	3·8
FeO . . .	2·9	8·9
MgO . . .	4·6	5·1
CaO . . .	**9·4**	8·4
Na_2O . . .	·8	2·7
K_2O . . .	1·3	1·3
H_2O . . .	**3·3**	1·7
CO_2 . . .	**12·7**	·2
TiO_2 . . .	1·8	2·2
P_2O_5 . . .	—	·2
MnO . . .	—	·2
	78·6	99·9

A.—Weights present in that amount of the altered Whin Sill (White Whin, analysis A, Table I), which was formed from 100 grams of average Whin Sill (analysis B, Table I), assuming that there has been neither gain nor loss of Al_2O_3.

B.—Average analysis of Whin Sill quoted from B, Table I.

(Numbers in heavy type indicate those constituents in which there is an ncrease during metasomatism.)

making improbable the first hypothesis of no change in volume despite the accurate preservation of the original texture, leads to a second hypothesis, namely, that there has been neither gain nor loss of Al_2O_3 during metasomatism. With this assumption column A, Table III, shows the weight of white whin which was produced from 100 grams of unaltered dolerite. Under B is given, for comparison, the average analysis of the Whin Sill. From these figures it is clear that 99·9 grams of unaltered dolerite of specific gravity 2·92 gives 78·6 grams of white whin, whose specific gravity has been determined as 2·73 : from this a simple calculation shows that 34·3 c.c. of dolerite became 28·8 c.c. of white whin, or that during metasomatism there was a reduction in volume of 16 per cent. The small scale chalybite veining which has been observed especially at localities 3, 4, 5, and 6 is to be regarded as a result of this contraction during alteration. A good example is found about a quarter of a mile below Winch Bridge in the bed of the Tees (locality 4), where the joints in the unaltered Whin Sill are closed, but within the extensive irregular areas of white whin, chalybite veins are abundant. In one case the width of a patch of white whin is about 10 inches and the total width of chalybite veins within the area about 1¼ inches; this corresponds with a reduction in volume of 12·5 per cent., a figure of the same order as the calculated one.

Using the more probable hypothesis of no gain or loss of Al_2O_3 during the alteration to white whin, a comparison of columns A and B, Table III, shows that the important changes of composition in the rock were loss of silica, ferrous and ferric oxides and soda and a gain in water and carbon dioxide. The solution, working through the pore spaces of the rock, must therefore have been aqueous, and have contained carbon dioxide, silica, soda, and iron. Besides the substances in the solution effecting the white whin metasomatism whose presence can be demonstrated, other substances (see Finlayson, 1910, pp. 307–8), ultimately deposited as the various lead vein minerals, must have been present in the solutions in the major openings in the dolerite. These may have been present in small amounts in the capillary pores of the rock at the scene of the various metasomatic reactions, but there is no evidence to show that they were actively concerned in the metasomatism.

The analysis of the white trap formed from the Mons Hill teschenite (Stecher, 1888, p. 172, and Flett, 1910, p. 312) shows so remarkable a resemblance to white whin that the similarity cannot be passed over without comment (see analyses E and F, Table I). Stecher calculated that the white trap consisted of 26·6 per cent. of carbonate, and 56 per cent. of kaolin, the remainder being muscovite, quartz, possibly some felspars, and titaniferous iron oxides. The minerals stable under the conditions of formation of the white trap from the Mons Hill teschenite are identical with those produced by the lead vein solutions, despite the differences in the geological events to which they owe their origin.

A marked feature of the bulk changes in composition during the formation of white whin is the loss of iron. Some of the iron was deposited again in the contraction cracks formed during the metasomatism, giving the chalybite veins already described. Some, however, seems to have influenced the general composition of the lead veins. Above the Whin Sill in the Yoredale beds, a quarter of a mile down stream from Winch Bridge on the south side of the Tees, there are several mineral veins which have been worked for iron. The veins consist for the most part of chalybite, but they also carry some galena, zinc blende, barytes, and calcite, and seem to be normal lead veins to which has been added enough chalybite to make them locally a source of iron ore. J. G. Goodchild and C. T. Clough in the *Survey Memoir* for sheet 97 N.W., page 168, wrote: " In the Swaledale district iron-ore is generally very rare and we have not noticed any undoubted instances of ' famped ' or decomposed limestones near veins : these rocks are probably closely connected and their absence in Swaledale is striking, considering how abundant they are in the adjoining and in many respects similar mining district of Higher Teesdale and Weardale." Iron ore is also rare in the lead veins of Wensleydale and Wharfedale, where, as in Swaledale, the Whin Sill is absent. It seems probable that the iron minerals in the lead veins of Teesdale and Weardale owe their origin to the metasomatism taking place as the lead vein solutions traversed the Whin Sill. Not only was the dolerite extensively altered in composition by the lead vein solutions, but the complementary change in composition of the solution was apparently sufficient tc produce a significant change in the contents of the lead veins above the Whin Sill.

THE TRANSITION BETWEEN WHITE WHIN AND THE UNALTERED DOLERITE.

In the field where exposures are favourable (localities 3, 4, and 5) there is found to be a transition between the altered and unaltered dolerite which extends over a distance of about 6 cm. Under the microscope the individual minerals may be seen to change over fairly abruptly in a centimetre or less, and the gradual transition observed in hand specimens is found to be the result of the successive alteration of the different minerals. In all the specimens showing the transition which have been examined, the order in which the minerals are successively altered has been found to be invariable, although the total distance occupied by the transition is not constant. As before, material from Winch Bridge (locality 5) will be chosen for detailed description.

The diagram (Fig. 1) shows the order of replacement for the various minerals measured from the point at which alteration can first be detected. The pyroxenes, the first to be attacked, are changed to a mixture of carbonate and an uncertain mineral which is probably related to gyrolite. The metasome is at first crowded with brownish inclusions which make optical determinations difficult, but if the carbonate is removed with acid the doubtful gyrolite can be seen to have a grain with respect to which the extinction is straight, a refractive index usually considerably less than balsam, a birefringence of about ·008 and a negative sign. It was not clear whether the mineral was truly uniaxial or biaxial with a small optic axial angle. Both rhombic and monoclinic pyroxenes are replaced by similar pseudomorphs, but the hypersthene changes over a little further from the limit of alteration than the hypersthene augite. In the space of a centimetre or so the gyrolite-like material is replaced by carbonate, and the pyroxene areas then consist solely of carbonates having a dark colour due to inclusions. About this stage hornblende is decomposed, for the most part to carbonate. Four centimetres from the limit of alteration the plagioclases begin to be replaced in their central and more basic part by kaolin and calcite, which are at first intimately mixed together. A little further on where replacement of the plagioclase is complete, quartz, often in optical continuity with surrounding quartz, may be observed among the calcite and kaolin. The carbonate from the plagioclase can be distinguished from that after ferromagnesian minerals not only by its situation but because it is free from the inclusions which crowd the latter. At about the stage at which the plagioclase is decomposed, the carbonate, replacing the pyroxenes, becomes aggregated into larger crystals, and the inclusions increase in size, until it is possible to make out something of their shape which is suggestive of

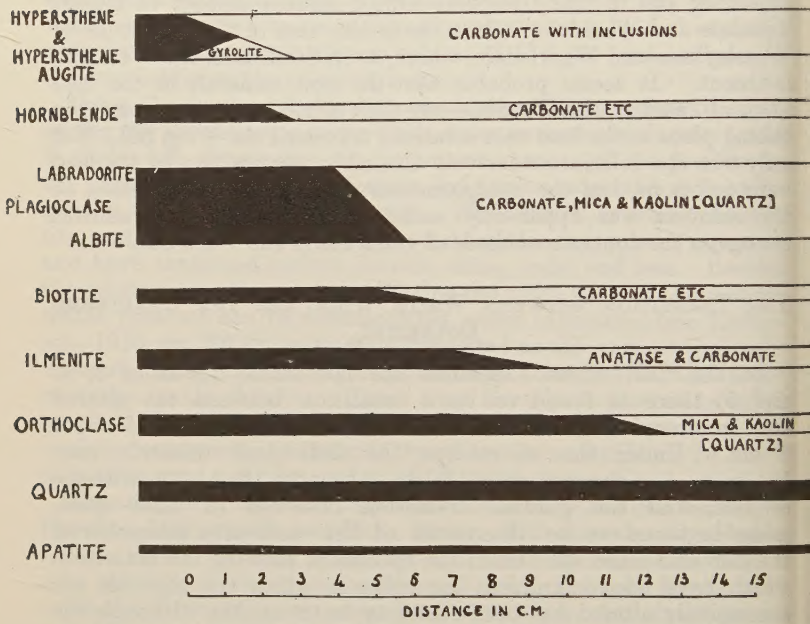

Fig. 1.—Diagram to show the transition between unaltered Whin Sill and white whin. Black represents the original minerals of the dolerite; white represents newly formed minerals. Distances are measured from the beginning of the alteration.

anatase. At about 5 and 7 cm. respectively from the beginning of alteration the biotite and ilmenite are replaced, and finally at a distance of 11 or 12 cm. the orthoclase disappears. In rare cases the orthoclase may be seen to be replaced by a micaceous mineral, possibly muscovite, showing apparently a higher double refraction than that of the kaolin replacing the plagioclase felspars, but more usually all that can be seen with certainty is that the plagioclase and orthoclase together, have been replaced by the minutely crystalline aggregate of micaceous minerals which have been referred to kaolin and mica. As in the similar pseudomorphs after plagioclase, quartz may sometimes be detected among the micaceous minerals replacing orthoclase. The original quartz of the dolerite either remains unchanged or is slightly increased in amount by partial replacement of the orthoclase and the acid outer border of the plagioclase by quartz which is in optical continuity with the original quartz of the dolerite. Apatite apparently remains completely undecomposed. By a general removal of the calcite from the kaolin-mica areas or by its aggregation into larger crystals, the slice takes on the appearance of a very exact replacement of the ferro-magnesian minerals by carbonate and of the felspars by a fine micaceous aggregate.

AN INTERPRETATION OF THE TRANSITION AND ITS BEARING ON THE MECHANISM OF REPLACEMENT.

In a section of the partly altered Whin Sill two or three centimetres from the first signs of alteration, the pyroxenes are seen to be completely replaced by carbonates, while the felspars are as fresh as in the unaltered rock (cf. Heslop and Smythe, 1910, pp. 6–7 ; Holmes and Smith, 1921, pp. 453–4). The pyroxenes must have been decomposed by solutions which reached them through minute cracks in and around the various minerals of the rock, and the solution must have come equally into contact with the unaltered felspars as with the decomposed pyroxenes. Since the temperature and pressure of the system during the metasomatism may be considered approximately constant, a difference in the composition of the solution must be regarded as the cause of the stability of the plagioclase at 3 cm. from the limit of alteration and its instability at 6 cm. (see Fig. 1). An approximate idea of the way in which the composition of a solution, occupying cracks and small openings in a rock which are too small to allow of free circulation, would vary with the distance from the open joint, may be deduced at once from the general principles underlying the phenomenon of diffusion. In order to produce the requisite diffusion of carbon dioxide into the dolerite where it was used up in forming carbonates, the concentration of carbon dioxide in the solution must have become steadily less from the open joint towards the scene of the metasomatic reactions. In the same way, to maintain the outward diffusion of the waste products of the reactions, in this case chiefly silica, soda, and iron, there must have been a decreasing concentration for these substances from the scene of the reactions within the rock towards the open joint. In this solution of steadily varying composition there would be an environment for each mineral between the open joint and a definite point in the region of the transition in which it would be unstable, and another environment at a further distance from the source of the solutions in which the same mineral would be stable. The main feature of the transition between altered and unaltered dolerite, namely the successive replacement of the different minerals, may, in this way, be explained as the result of the change in concentration of the solution which was caused by diffusion in the capillary openings of the solid rock.[1]

At the stage in the transition represented by the line through 11 cm. in Fig. 1, the occurrence of orthoclase surrounded by decomposed plagioclase indicates that, although orthoclase was stable in a solution of certain concentrations of CO_2, SiO_2, and alkalies, plagioclase was decomposed. It has just been shown that during the metasomatism, the greater the distance from the source of the solutions the less was the concentration of the CO_2 and the greater was the concentration of alkalies and silica. Changes in this direction eventually produced an environment from 0–4 cm. in Fig. 1 where plagioclase became stable. If we tentatively express the decomposition of the plagioclase by such an equation as :—

$$\text{(albite + anorthite)} + CO_2 + H_2O \leftrightarrows \text{kaolin} + \text{calcite} + \text{alkalies} + SiO_2$$

it is clear from the chemical law of *mass action* that a decrease in the concentration of CO_2 and an increase in the concentration of the alkalies and calcite are processes which would be expected to stabilize the plagioclase. The law of mass action explains how changes in the concentration of the substances in solution may be considered to control the stability of the various minerals and thus produce the observed transition between altered and unaltered dolerite.

In an explanation of this kind, however, a difficulty arises because the silica, formed from decomposition of the silicates, is removed from the rock, while crystalline quartz is undissolved or even slightly increased in amount. The solution of silica produced by the decomposition of the silicates may perhaps be to some extent colloidal, although not so much so as to prevent diffusion. The law of mass action could not be applied to such a solution in contact with silicates or quartz without modification, and probably deposition of quartz y such a solution would be a slow process even compared with the ong period of time required to produce the diffusion necessary for he observed metasomatism. Some such supplementary hypothesis eems to be required to avoid the apparent anomaly of the removal f SiO_2 from the rock with a slight simultaneous increase in the mount of crystalline quartz.

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[1] In the case of an igneous rock such as the Whin Sill, the openings here postulated are probably those through which the residual gases or liquids of the magma escaped at a late stage in the cooling process. On *a priori* grounds a metamorphic rock would not be expected to have such abundant small openings.

Data are scanty which would enable a discussion of the particular hemical equilibria concerned in the formation of white whin, ut the fact that ferrous carbonate is more soluble in alkaline arbonate solutions than is calcium or magnesium carbonate (cf. Reynolds, 1898, p. 265, and Mellor, 1923) may explain why iron was eached out of the rock and yet was deposited as soon as the open oints were reached. The solution in the open joints was relatively ich in carbon dioxide and poor in alkalies, but the change in conentration from the joint to the scene of reaction resulted in a elative increase in the alkalies and a decrease in carbon dioxide. Within the rock, in the presence of the increased concentration of lkalies, ferrous carbonate was more soluble than calcium or nagnesium carbonates, while in the joints where the concentration f the alkalies was lower, ferrous carbonate would tend to be preipitated. Experimental work on the interaction at fairly low temerature of the minerals of an igneous rock with aqueous solutions, which at first sight might have provided data for discussing some of he other changes which have taken place in the formation f white whin, has been found to have little bearing on the roblem. For instance, Stephenson (1916) in his experimental work on hydrothermal alteration of felspars, hornblende, etc., eated these substances with aqueous solutions that were so ilute that equilibrium conditions were not reached. Dilute solutions were used because he considered from the evidence f ground waters and hot springs that under natural conditions elatively dilute solutions were the active agents. In metasomatism, where the reactions take place in the capillary spaces of a rock, the solutions vary up to saturation point for certain constituents, nd the equilibrium conditions would provide far more valuable xperimental data for the interpretation of such cases of metasomatism s that of the white whin.

The transition between altered and unaltered dolerite shows that he decomposition of a mineral is controlled by the concentrations f the reacting substances in the solution at the point where reaction s in progress. Goldschmidt (1922, pp. 118–22) has reached the same onception from a theoretical point of view by using the law of mass ction and he has expressed it thus: "A solution, in order to effect metasomatism, must contain the substances to be added in concentraions at least equal to a minimum, which is definite for each case." Of equal importance is the further generalization, also illustrated y the formation of white whin, that the metasomatic alteration f a mineral will cease if the concentration of the waste products of the reaction exceeds a certain maximum value which is definite for each case. These general statements apply not only to the solution at the actual point at which reaction takes places but also, in theory at any rate, to the solution in the open joints where fairly free circulation is possible. If, however, the concentration in the larger openings in the rock is only slightly above the minimum value required by Goldschmidt's generalization, the concentration-gradient between the scene of reaction within the rock and the open joints will not be steep and diffusion will therefore be slow, so that even after long periods of time there will not be any large amount of metasomatism. In the same way if the concentration of the waste products of the reactions in the joints approaches the maximum that will allow of metasomatism, diffusion outwards will be slow and the amount of metasomatism will again become almost negligible. Even if the concentration in the open joint is appropriate for rapid replacement, the rate must of necessity be greatly reduced as the distance between the scene of the reaction and the open joint increases ; the greater this distance the less steep is the concentration gradient and diffusion therefore becomes slower. The chemical principle of mass action sets the first and most fundamental limit to metasomatism, but the laws governing the rate of diffusion in capillaries sets the limit to the extent of metasomatic changes.

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EXPLANATION OF PLATE XI.

Fig. 1.—Unaltered Whin Sill, Winch Bridge, near Holwick, in Teesdale (locality 5), showing typical sub-ophitic texture. Magnification × 60.

Fig. 2.—Altered Whin Sill (White Whin), Winch Bridge, near Holwick, in Teesdale (locality 5), under partly crossed nicols, so that carbonates after ferromagnesian minerals are dark grey, micaceous areas after plagioclase are light grey, and original quartz areas are white. Magnification × 60.

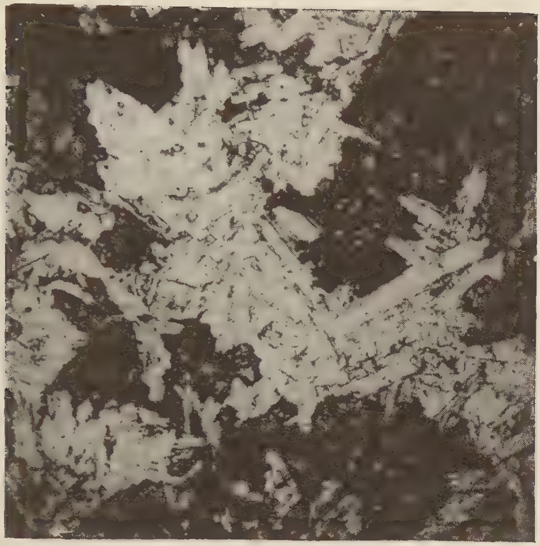

FIG. 1.

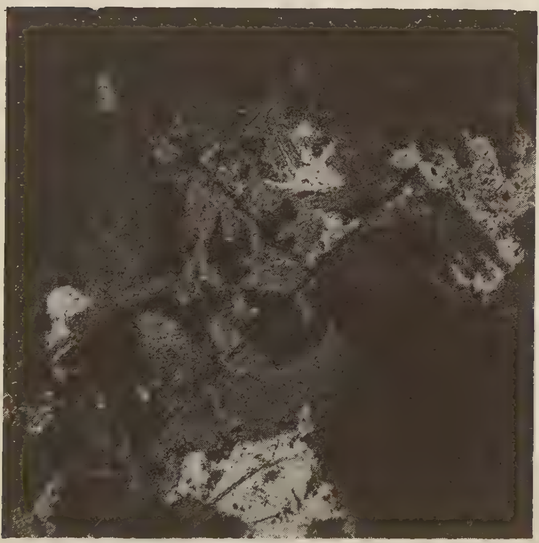

FIG. 2.

A COMPARISON OF THE TEXTURES OF NORMAL WHIN SILL (FIG. 1) WITH ALTERED WHIN SILL (*WHITE WHIN*) (FIG. 2).

[*To face p. 110.*

Rock Crystal and Diamond Pipes in Brazil.

By Robert R. Walls, M.A., B.Sc.

IT is now eight years since the present writer drew attention in these pages to his discovery of a diamond-bearing pipe of gneous origin in Brazil (3).[1] The matter, though hotly contested and denied at the time, seems now to have been generally accepted. So much so in fact that Dr. Alex. du Toit, in his presidential address to the Geological Society of South Africa (10) compares the diamond-bearing pipes of Brazil and South Africa as an indication of the former close connection of these lands.

Now, considering the immense amount of wealth to be obtained by the discovery and exploitation of diamond pipes, it is curious to reflect that to-day, eight years after the announcement of the discovery of true pipes of igneous origin bearing diamonds, the three pipes mentioned by the present writer at that time, are still all that are definitely known to exist in Brazil. The pipes referred to are those at Sopa, Boa Vista, and São João do Chapada, all close to the town of Diamantina in Minas Geraes. When we consider the intensive development of the diamond-bearing pipes of South Africa, and the wealth they have contributed to the state, this dilatoriness on the part of Brazil to develop her diamond mines seems unaccountable.

The reasons are many and varied. Perhaps the chief is that Brazil is the land of "Amanha"—To-morrow. Nothing is ever done to-day which can be put off till to-morrow. Another very mportant reason is the complexity of the mining laws, which vary n the different States, and which give little or no security of tenure to miners, especially if these are foreigners. The whole country s for the most part still wild and lawless and badly needs a strong executive police force. The government survey departments are totally inadequate, and most of the maps published, geographical and geological, have been the work of outsiders (4), (6), (7). In short the country is still in a very primitive state, and it will be very many years yet before Brazil enjoys the benefits of a strong government and industrial and social organization.

We can now understand why it is that so little has been done n the way of searching for and exploiting the diamond pipes of Brazil. It is quite possible and even probable that other pipes are known, but the discoverers are not publishing anything about them. They prefer to work them quietly after the primitive style of the country, and reap what benefits they can at once. Much useful information is thus being lost to science. Dr. du Toit, in his paper quoted above, draws attention to some points of similarity between the pipes of Brazil and South Africa, and the present writer would like to supplement these by various observations made when he first discovered the Sopa pipe in 1919 (2), (11). It would appear also that there are some points in which the pipes of the two countries vary, but of these Dr. du Toit says nothing.

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[1] Figures in parentheses refer to Bibliography at end of paper.

Let it be said at once that the discovery of diamond-bearing pipes in Brazil by the present writer was made quite accidentally. While searching for the pure variety of quartz known as rock crystal the writer followed the trail of pebbles in the river gravels right up on to the highest part of the high plateau. The fundamental rock of these regions is granite and gneiss—the " fundamental complex " of the Brazilian geologists. But on this granite plateau there exist long ridges of quartzite (6). Tectonically there are only two ridges —the Serra do Espinhaço on the eastern margin of the State of Minas Geraes, and the Serra do Canastro along the western margin. These ridges are not always continuous, however, and sometimes they appear as a string of minor ridges, each having its own name locally. These ridges stand out more or less conspicuously, sometimes even with comparatively steep escarpments 1,000 feet or more in height, above the general level of the plateau (7).

Previous to the writer's visit to Brazil the exploitation of the rock crystal was entirely in the hands of Germans and our entire knowledge of its mode of occurrence was due to German sources. It was reported as occurring in drusy cavities in granite, just as we find it in the granites of this country. It was a great surprise for the writer therefore when he followed the trail of crystal pebbles from the granites up into the overlying quartzites, and a still greater surprise to discover that the pure rock crystal did not occur in drusy cavities in granite at all, but was a metamorphosed quartzite.

The quartzites were typical sandstones, filled in with secondary quartz, but in certain areas great modifications of the quartzites were found. Sometimes, where bleached pure white, they resembled marble. At other places they are quite friable and crumble to an exceedingly white powder. Sometimes, when pierced by sericite veins they take on a schistose appearance, but the lamination was then found in two distinct directions at right angles to one another. The laminae are either horizontal and parallel to the bedding planes or vertical and parallel to the joint planes. Where pure rock crystal occurred it is always found in the bedding planes or in the joint planes.

The crystal is purest in these planes and a gradual transition can be traced to the ordinary granular quartzite adjoining. The crystals are always definitely oriented with regard to the bedding planes—the long axis of the crystal being always perpendicular to the bedding plane. Even below the pure well-formed crystal of quartz the planes of the crystal faces could be traced running down vertically across the bedded quartzites and giving it therefore a columnar structure like basalt. The rock could be split down naturally along these planes of incipient crystallization just as easily as along the bedding planes, and it was a comparatively easy matter therefore to quarry out the crystal.

When the crystal was found in vertical joint planes the long axis was usually horizontal, i.e. again at right angles to the joint plane. The planes of the crystal faces could then be traced running parallel with the bedding planes. This was not a common feature, however. Sometimes, where bedding planes and joint plane intersected, something like a drusy cavity was produced. It was filled with small crystals tilted at all angles to each other. This is much more common. The writer obtained two excellent hand specimens of such, showing the gradual transition from pure rock crystal down into granular quartzite, and one of these is now on view at the British Museum at South Kensington (2).

One crystal was taken for microscopical examination. It was about the size of the small finger of the adult hand, and showed a clear hexagonal crystal capped by the usual pyramid at its upper end, and granular quartzite at the base. The quartzite was very friable always just below the area of crystallization, so the crystals could always be pulled out easily. This particular crystal showed two clear lines in the granular basal portion. These represent minor bedding planes in the quartzite. This crystal showed therefore on a small scale the whole phenomenon of the recrystallization of the quartzite. When cut in longitudinal section and studied under the petrological microscope, however, the apparently granular portion of the base proved to be part and parcel of the one crystal. The tiny grains were all arranged in optical continuity. Included, however, were many tiny crystals of what appeared to be sericite, these being far more numerous in the granular basal portion than in the clear crystalline part. Most specimens of rock crystal when examined carefully under the microscope show tiny inclusions of sericite.

The crystal examined showed no granular quartzite whatever at the base. But, as has already been noted, the quartzite is very friable just below the crystalline portion, and any granular quartzite is easily broken away. The rough handling to which the crystal was subjected in transport had removed all the loosely cohering grains, and nothing remained but the single crystal. It would be quite possible with care to extract a single crystal with sufficient granular quartzite in the base to show in micro section the whole transition from granular quartzite to crystal.

The nature and occurrence of this recrystallized quartz along seams and bedding planes seemed to indicate that the rock had undergone metamorphosis by the action of heated vapours. The source of the heated vapours was not difficult to find. The first rock crystal formations discovered by the writer all lay round a huge excavation—the Sopa diamond mine. Thus, quite casually, the writer discovered a true igneous pipe, bearing diamonds, in Brazil, similar to the diamond pipes of South Africa, at least in their general respects (3).

The Sopa diamond mine was not regarded as a pipe at that time. Its igneous origin was not recognized. It was supposed to be an ordinary alluvial deposit, and was in fact worked as such. A tiny stream—one of the tributaries of the Jequitinomha river—flowed through it and served as a water supply for washing the diamond-bearing soil. Weathering had reduced the material of the pipe to a soft unctuous white clay to a depth of 50 feet at least. Below this appeared a harder greenish-white rock. The mine had been dug out like a huge hollow, bounded at its extreme edges by the hard quartzite cliffs. The cutting extended for nearly a mile in length, and certainly at first glance might have passed for an ancient valley filled with alluvial deposit (1).

At the time I made this discovery I had never seen the South African pipes, and knew nothing about kimberlite at first hand. Yet it struck me at once that this white unctuous clay was nothing more than a very much weathered kimberlite. The cutting at Sopa was nowhere deep enough to enter the less weathered rock, and no attempt was being made then to cut any deeper in search of diamonds. The harder rock was regarded as the old river bed, and only the soft highly weathered portion was being dug out and washed for diamonds.

Luckily just at this time I ran across Mr. Draper, an experienced South African geologist, who had just discovered a similar pipe at Boa Vista, some 20 miles away on the opposite side of Diamantina (5). At his invitation I visited the Boa Vista mine, and my opinions were confirmed. These two mines were really in pipes of igneous origin and not in the alluvium of old river valleys (8).

Many of the phenomena round the Boa Vista mine were exactly similar to those at Sopa. The quartzites round the margin had been bleached white in some places into the so-called marble, and sericitic veins traversed the country rock for long distances from the pipe. I saw no evidence of the metamorphosis of the quartzite into rock crystal at Boa Vista, however, though I looked for this phenomenon particularly. This does not mean of course that it may not be discovered yet. Weathering all over the high plateau has proceeded to a great depth and the country as a rule is covered with a thick sedentary soil with comparatively few rock exposures.

In place of rock crystal, however, another phenomenon manifested itself in the quartzites surrounding the Boa Vista mine. Where these were most friable and traversed by sericitic veins, a perpendicular lamination seemed to be visible across the former horizontal bedding. If some of these laminations were extracted carefully from the crumbling quartzite they were found to be quite pliable and springy. They had the appearance of a soft weathered schist, yet there was no tectonic foliation in the rock. The notable feature was that this lamination was always more or less vertical and at right angles to the bedding planes. As has already been explained the crystals of pure quartz round the diamond mine at opa were also growing perpendicular and at right angles to the edding planes of the quartzite.

Perhaps these two cases illustrated above give us the explanation f the peculiar metamorphosis of the quartz into rock crystal. ot gases or hot solutions emanating from the pipe traverse the eams and bedding planes, and, permeating the quartzites along ese channels, act as a flux, first softening the hard quartz, and en rearranging the tiny crystals into optical continuity to form ne big crystal. The flexible sandstone found at Boa Vista may e simply the first stages in the conversion of quartz to rock crystal. t other points this metamorphosis has proceeded much farther, nd gigantic crystals have been formed. The largest crystal which he writer saw and photographed in Brazil weighed 13 cwt.

One fact which comes out of this discovery is that rock crystal a satellite of the diamond in Brazil, though it has been produced ot in the pipe itself, but by metamorphosis of the quartzites ound the margin. Rock crystal, in the form of pebbles, is always ound in association with the diamonds in the river gravels and placer ines. Yet rock crystal is never spoken of as a satellite of the iamond in Brazil, and is never even mentioned in South Africa.

The writer, during a very hurried visit to South Africa in 1920, nspected some of the diamond mines there, but could find no trace f the metamorphosis of the quartzites such as he found in Brazil. t would be interesting to hear from geologists of greater experience hether such phenomena as noted above had ever been noticed t all in South Africa. The non-appearance of such phenomena n South Africa would at once indicate a greater variation in the etrological characters of the sedimentary rocks or of the igneous ntrusions which pierced them, than is accepted by Dr. du Toit in his aper noted above (10).

This association of rock crystal and diamonds is not confined o the three pipes already mentioned as occurring on the Serra o Espinhaço in the neighbourhood of Diamantina. Along the estern margin of the State of Minas Geraes runs a ridge similar to and arallel with the Serra do Espinhaço. This western ridge is not quite o conspicuous as the Serra do Espinhaço and is interrupted and roken into a series of minor ridges each having its own local name. ectonically it is similar in all respects to the Serra do Espinhaço, nd is likewise composed of more or less horizontal beds of hard uartzite overlying the granite and gneiss. I have used an old ame, the Serra do Canastro, found in early geographical works, o designate the whole ridge. The quartzites in the Serra do anastro have been modified in a similar fashion to those in the erra do Espinhaço, and all the varieties of "marmor" are found here also, as well as the more friable varieties of quartz and rock rystal. The Serra des Cristaes or Crystal Mountains show the atter metamorphosis on a very extensive scale, and the Serra des ristaes is really part of the Serra do Canastro. Diamonds have been found in association with the rock crystal in these localities as well as most of the other satellites of the diamond.

In conclusion therefore I would point out that in Brazil the appearance of rock crystal and the peculiar metamorphosis of the quartzites would be the best indication of the existence of pipes of igneous origin and potentially diamondiferous. And, since in the high plateau the weathering of the rock has been deep and intense and the soil more or less sedentary, it is most probably those indications which will lead prospectors in the future to locate still more pipes in Brazil.

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The Classification of a Glassy Rock: The Pitchstone of Wormit, Fifeshire.

By S. J. Shand, Stellenbosch, South Africa.

I.

In most systems of petrography the glassy rocks are treated in a very casual way. The names which are commonly given to them, such as obsidian, pitchstone, perlite, vitrophyre, and the like, afford no reliable indication of composition; and when a rock is partly crystalline and partly glassy, the composition of the glass is often assumed, quite unwarrantably, to be the same as that of the crystals. It is only in the Norm classification that vitreous rocks fall unfailingly into the same compartments as holocrystalline ones of similar chemical composition; and before any rock can be classified by this method, it is necessary to have a complete chemical analysis of it; which is, for many workers, a serious obstacle.

It is the purpose of this paper to show, by a concrete instance, that glassy rocks can often be classified by quite simple means; and in particular that the quantitative mineralogical classification lately put forward by the writer,[1] can be applied to many glassy rocks almost as easily as to holocrystalline ones.

It should be observed, in the first place, that many glassy rocks have been analysed in the past; quite enough to furnish valuable generalizations regarding the relative abundance of different types. From 124 analyses of glassy and partly glassy rocks which are scattered through the pages of H. S. Washington's well-known tables, the following deductions emerge :—

(i) At least 80 per cent of all such rocks are oversaturated with silica to the extent of more than 10 per cent, and consequently fall in the oversaturated class of the writer's system. More precisely, 49 per cent are soda-rhyolites, 15 per cent potash-rhyolites, and 16 per cent dacites in terms of the system referred to.

(ii) Nine per cent of the analysed rocks contain from nothing to 10 per cent of free silica, and consequently fall in the saturated (and transitional) class of the system.

(iii) Eleven per cent of the analysed rocks are undersaturated with silica.

(iv) At least 85 per cent of these rocks are leucocratic (i.e. the calculated norm contains the equivalent of less than 30 per cent of heavy minerals).

These figures show that, roughly speaking, nine glassy rocks out of ten are rhyolites, dacites, or trachytes. The remaining one-tenth is mostly made up of tachylytes (basaltic glasses) which never form bodies of any geological magnitude and for which, in consequence, a precise name is hardly necessary.

For the distinction of rhyolitic, trachytic, and dacitic glasses from one another, the following methods are available.

(i) *Specific Gravity.*—From data collected by C. E. Tilley and others,[2] it appears that the commoner types of rhyolitic obsidian have S.G. 2·3 to 2·4. The peralkaline type, which contains soda-ferric molecules such as acmite, may nevertheless have S.G. 2·5 or more. Trachytic glasses have S.G. 2·4 to 2·5, or still higher values in the case of the peralkaline type. For dacitic and andesitic glasses sufficient data are lacking, but their density should be a little higher than that of rhyolites. The basaltic glasses, owing to their large content of heavy molecules, have S.G. greater than 2·7.

(ii) *Refractive Index.*—Tilley gives the following data: rhyolitic obsidians, 1·482 to 1·495; trachytic obsidians, 1·506 to 1·512; basaltic glasses, 1·576 and upwards. Data for andesitic and dacitic glasses are lacking.

(iii) *Flame Reaction.*—Bunsen[3] showed that the soda and potash content of an unknown mineral can be estimated by comparing its

[1] *Eruptive Rocks*, London (T. Murby and Co.), 1927.

[2] *Mineralogical Magazine*, 1922, p. 275.

[3] *Annalen der Chemie und Pharmacie*, 1859.

flame reaction with those of minerals of known composition. The procedure was elaborated by Szabo,[1] who published a series of coloured plates for comparison with the observed flames, but I have not found these serviceable. To apply the method either to a felspar, a rock-glass, or a stony groundmass, it is best to prepare a series of very finely powdered mixtures of potash-felspar and soda-felspar, containing various known proportions of Or and Ab. Two clean platinum wires are dipped into pure water (*not* into acid) ; a little of the unknown mineral (in very fine powder) is taken up on one wire, and a little of one of the known mixtures on the other ; then the tips of the two wires are brought simultaneously into the Bunsen flame from opposite sides and the colouration is studied through a cobalt glass. As this procedure requires three hands, it is advisable to make holders for the platinum wires out of stout knitting needles or glass rods, with corks sliding up and down on them. The comparison should be made in a dark room, and practice is necessary to accustom the eyes to the very slight differences in the intensity of the colour.

(iv) *Microchemical Tests.*[2]—The powdered glass is covered with a drop of hydrofluosilicic acid on a strip of celluloid ; dried on a water-bath ; and examined for the characteristic crystals of the alkaline silicofluorides and afterwards for the chloroplatinates. Potassium silicofluoride forms isometric crystals which, after treatment with hydrochloric acid and platinum chloride, yield octahedrons of potassium chloroplatinate, insoluble in alcohol. Sodium silicofluoride forms hexagonal prisms which are optically negative. With hydrochloric acid and platinum chloride, sodium chloroplatinate is formed, which is soluble in alcohol. Calcium silicofluoride is monoclinic ; treated with sulphuric acid, it gives blades of gypsum.

The above considerations indicate that it should be possible to classify all except the rarest (and geologically least important) varieties of glassy eruptive rocks by simple methods not involving quantitative chemical analysis.

II

To demonstrate this practically, I undertook, with the assistance of Mr. M. S. Taljaard, a senior student in my department, an investigation of the pitchstone of Wormit, Fifeshire, which was described by Mr. James Durham[3] in 1886. This rock, which Professor Judd considered to be a dacite-pitchstone or mica-dacite glass, is a dark grey perlitic glass holding about 5 per cent of little felspar insets[1] and a few scales of black mica. Under the microscope it shows the following characters.

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[1] J. Szabo, *Ueber eine neue Methode die Feldspathe auch in Gesteinen zu bestimmen*, Budapest, 1876.

[2] E. Boricky, *Archiv der naturw. Landesdurchforschung von Böhmen*, Bd. iii, Abt. v ; Prag, 1877 (see also works of Rosenbusch and Iddings).

[3] *Quart. Journ. Geol. Soc.*, vol. xlii, 1886, p. 418.

The felspar insets are plagioclase, giving symmetrical extinction angles of zero to 4·5 degrees. The lowest refractive index is close to the index of Canada balsam, while the highest is less than 1·545. These observations indicate that the composition is about $Ab_{82}An_{18}$. Besides these larger crystals of felspar, the glass contains a multitude of felspar microlites, which were estimated, by means of the recording micrometer, to make up 7·5 per cent of the rock. Professor Judd assumed that these microlites were orthoclase, but some of them distinctly show polysynthetic twinning, and the mean refractive index is slightly higher than that of Canada balsam. The extinction is wavy, so it was not possible to make exact measurements of the extinction angle in symmetrical sections, but the angle appeared to be the same as in the larger crystals. Those microlites which do not show polysynthetic twinning extinguish obliquely to their length, at a maximum angle of 9 degrees. It follows that the majority of the microlites are plagioclase with a composition similar to that of the insets.

The mica is a dark, greenish-brown biotite. The scales enclose grains of iron ore and apatite, and are themselves occasionally enclosed in the felspar insets. Although mica scales are conspicuous on broken surfaces of the rock, the actual proportion of biotite is less than 2 per cent.

Brown iron oxide, in dustlike grains, rodlets, and quadratic sections, is scattered scantily through the glassy base.

The glass, which constitutes about 86 per cent of the rock, is isotropic and almost colourless in thin section, but where it has been exposed to weathering it breaks down to a white powder. When ignited, it gives up more than 8 per cent of water and forms a pumice. The density of the glass (containing microlites) was found by Mr. Taljaard to be between 2·281 and 2·289 (flotation method), and its refractive index about 1·496 (immersion method).

For the density of the entire rock, Mr. Taljaard found 2·30 at 18 degrees (pycnometer method). Making a correction for the water contained in the glass, the density of the anhydrous rock should be about 2·44.

III

We may now proceed to consider the classification of this unusual rock. The refraction and the density are nearly those of a rhyolite, from which we may infer the presence of an excess of silica in the rock. Since the felspar insets have the composition $Ab_{82}An_{18}$, one would expect the glassy residue to be still richer in albite. Flame tests show soda in considerable excess over potash (Mr. Taljaard estimated nearly four times as much albite as orthoclase), and this conclusion is confirmed by microchemical tests. The only point about which there is some doubt is the proportion of lime in the glass. If Professor Judd's opinion, that the microlites are of orthoclase, were correct, it would indicate that practically the whole of the anorthite is contained in the insets, in which case the glass base—constituting 86 per cent of the rock—must be almost a pure albite-orthoclase-quartz glass. Such a rock would not deserve the name of dacite at all. That Professor Judd should have called it a dacite, in view of his own observations, only shows how illogically rock names have been given in the past. But the microlites, as far as I can judge, are largely or entirely plagioclase; consequently one may not assume that the crystallization of anorthite has been completed. This complicates the problem, for it is not easy to judge how much anorthite is contained in the glass, apart from the microlites; but both the density and the refractivity of the glass are inconsistent with a large content of anorthite. It is probable, then, that orthoclase exceeds anorthite in the rock, and it is certain that albite largely exceeds both.

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[1] *Insets* (my terminology) are the " phenocrysts " of those who prefer bob-tailed Greek to plain English.

It follows from these data that the rock is a soda-rhyolite, probably belonging to the subdivision that I have called rhyodacite. Further, since biotite is the only dark silicate developed, the rock is peraluminous; and it is obviously leucocratic.

IV

The next step was to test the above conclusion by making a chemical analysis of the rock. Mr. Taljaard carried this out under my supervision, with the following result.

SiO_2	68·26	
Al_2O_3	14·05	
Fe_2O_3	1·12	
FeO	·23	
MgO	·07	
CaO	2·01	
Na_2O	4·09	
Na_2O	4·09	4·04
K_2O	1·90	1·82
H_2O-	·94	
H_2O+	7·37	
P_2O_5	·06	
	100·10	

The norm of this rock works out as follows:—

Quartz	32·8	Enstatite	0·2
Orthoclase	11·1	Magnetite	·7
Albite	34·6	Hematite	·6
Anorthite	9·7	Apatite	·1
Corundum	1·6		

The symbol of the rock in the norm classification is i, 4 (3), 2, 4 (lassenose). If instead of corundum we reckon phengite, the base of the mica group, then quartz is reduced to 31 and we have 3·8 parts f phengite. In the writer's classification such a rock is a *eraluminous soda-rhyolite* (variety *rhyodacite*), just as the preliminary xamination indicated.

It must be admitted that if a large proportion of mica were formed y the crystallization of this rock, the proportion of orthoclase would uickly be reduced to less than that of anorthite, in which case the ock would be a dacite. But an element of doubt must always ttend any speculation about the potential crystallization of a rock lass. It is sufficient that the result of the preliminary examination f this rock is fully confirmed by the chemical analysis.

The Ordovician and Silurian of the Carnic Alps.

y Franz Heritsch, Professor of Geology in the University of Graz, Austria.

THE Carnic Alps, the summit-ridge of which is the frontier between Austria and Italy, are famous for their Palaeozoic formations, hich contain large and beautiful faunas of Ordovician, Silurian, evonian, Upper Carboniferous, and Permian age. The Carnic lps form a very important part of the whole Alpine region, because hey display clear evidence of Palaeozoic orogenesis ; for example, he Taconic orogenesis between Ordovician and Silurian (which is f relatively little importance), and some phases of the Variscan rogenesis (between Devonian and Upper Carboniferous, and between he limestone of Trogkofel, which is equivalent to the stage of rtinsk, and the Lower Permian).

I propose to consider the stratigraphy of the Ordovician and ilurian of the Carnic Alps. These systems have been studied y the first explorer of the Alpine Palaeozoic rocks, G. Stache. ince his work, F. Frech and G. Geyer have produced notable reatises. Both of these excellent Alpine geologists have established tratigraphical divisions, of which that of Geyer is of greatest mportance for modern studies.

For the last twenty years the Italian geologists M. Gortani and . Vinassa de Regny have worked in the Carnic Alps. Vinassa e Regny has given some descriptions of the fauna of Caradoc ge and of the beds with *Rhynchonella megaera*. Both Italian nvestigators have given a description of a fauna from the Silurian imestone (Obersilur of the Alpine geologists).

But the stratigraphical divisions of the Italians are not clear. hey have adopted a varying subdivision, for example, one bed s considered as representing the whole Silurian, but a little later s representing only the uppermost Silurian. Hence arose an ncertainty in the stratigraphical divisions of the Carnic Silurian.

In recent years I have studied the important Silurian fauna f the mountain of Kok in the Eastern Carnic Alps, and also other maller faunas. I have had the advantage of many excursions in the very beautiful mountains of the Carnic Alps and have made myself acquainted with the Silurian of Bohemia and of the Harz in Germany.

This enables me to give a stratigraphical account of the divisions of Ordovician and Silurian of the Carnic Alps.

The Ordovician (Untersilur, Lower Silurian of the Alpine geologists) consists chiefly of shales and sandstones. Only a small part of the Ordovician consists of limestone, the so-called Tonflaserkalk.

The Ordovician fauna is similar in character to the British. Frech (1894) established this fact, although he had only a very small number of fossils to compare. More recent studies upon the fauna (by Vinassa de Regny and my own as yet unpublished descriptions) confirm the results of Frech and demonstrate clearly that there are only very slight relationships with the stages dα–dξ of Bohemia.

This limited connection with the Bohemian Ordovician is clear from the composition of the fauna: in the Alpine Ordovician the brachiopods preponderate notably. In the stage of *Calymene tristani* in Spain and in the British Caradoc the brachiopods have little or no connection with those of the Bohemian stage. On the other hand the trilobites are related.

On account of this preponderance of the brachiopods in the Alpine Ordovician, the stratigraphical stage of these beds is a little uncertain. The Italian investigators state with certainty that the Alpine Ordovician belongs to the Caradoc; but it is possible that older stages are present in the Ordovician. The Italians appear to base their views mainly on brachiopods.

Orthis and *Strophomena* preponderate in the fauna. The most common species are:—

Orthis actoniae.
,, *testudinaria.*
,, *vespertilio*
,, *noctilio.*
,, *porcata.*
,, *alata.*

Orthis calligramma.
,, *calligramma* var. *subplicata.*
Strophomena grandis.
,, *expansa.*
Porambonites intercedens var. *filosa.*

Besides the brachiopods there are many bryozoa, but these have not the same stratigraphical value, because the bryozoa of the Upper Ordovician have not yet been studied in Britain and in other countries with the same facies.

The exact age of these brachiopod-bearing rocks has now been clearly established by the recent discovery of another fossil. During an excursion which I led in the valley of Uggwa in the Eastern Carnic Alps, a young Englishman, Mr. Roger Quirk, of Winchester, found a trilobite in the brachiopod shales. I have determined this as *Dalmania socialis* Barr. var. *proaeva* Barr.

This trilobite, like many of those of the stage of *Calymene tristani* and like several from the English Caradoc, belongs to the Bohemian fauna. It demonstrates that the rocks with the brachiopods belong to the stage $d\epsilon$ of Bohemia and therefore to the Caradoc. The discovery of this trilobite does not exclude the possibility that there are older horizons in the fossiliferous Ordovician in other parts of the Carnic Alps.

In the uppermost part of the Ordovician is the so-called Tonflaserkalk. This rock consists of round clots of limestone which are surrounded by material which is in the main clayey. The clay arches round the clots of limestone. It proved possible to demonstrate that the latter are in part cystoids.

Except for these cystoids there are only *Orthoceratidae* in the Tonflaserkalk, and until now they have been indeterminable.

The Tonflaserkalk belongs to the Ashgillian. Above the Tonflaserkalk a few feet of shales are found.

Professor Boswell of Liverpool has visited with me the famous section of the Cellonetta in which the Ordovician is displayed. He was astonished at the general similarity of this Alpine Upper Ordovician to the British deposits.

Above the Ordovician the lowest beds of the Silurian are absent, at least, the zone of *Diplograptus acuminatus* (and perhaps also the zone of *Diplograptus vesiculosus*) is not present. This is the evidence of the Taconic orogenesis.

The Silurian (Obersilur, Upper Silurian of the Alpine geologists) consists chiefly of limestones with Orthocerates, limestones with corals, and shales with graptolites. It is a strongly developed formation, famous for its many beautiful fossils.

F. Frech (1894) has attempted a comparison with the Bohemian Silurian and has divided the Carnic Silurian into the following stages :—

$e\beta(E_2)$. Red limestone with *Orthoceras alticola.*
Dark limestone with *Orthoceras potens.*
$e\alpha(E_1)$. Black limestone with *Camerocrinus*, shales with graptolites.

The limestone with *Camerocrinus* is not the lower part of the Silurian, as Frech thought ; for new studies have established the fact that this limestone is the uppermost part of the Silurian ($e\gamma$).

The result of recent studies by Gortani and Vinassa de Regny have shown that *Orthoceras potens* and *Orthoceras alticola* are not fossils characteristic of a separate zone, for they are also found together in the same bed.

My own recent work when published will demonstrate the perfect agreement of the Carnic limestone fauna with that of stages $e\alpha$ and $e\beta$ of Bohemia, More than 90 per cent of the species are common to the Bohemian fauna.

When, therefore, I tried to use the Bohemian distribution of fossils in the Carnic Silurian, the attempt was almost abortive.

If the distribution of the fossils according to the great work of Barrande, is consulted, the important fauna of the limestone of Kok would be situated in the stage E_2 (= eβ). The same result follows from the application of the new distribution of the fossils made by Koliha, Kodym, and Perner.

But these limestones, which fall into the stage eβ, according to the Bohemian distribution of the fossils, are situated below the *dubius*-beds, for they contain *Monograptus priodon* (= eα 2).

Thus the Bohemian faunal distribution of fossils cannot be satisfactorily used for the Carnic Silurian. The first reason for this is the great similarity of the Bohemian fauna in the stages eα and eβ—without regard to the graptolites. Moreover, a second reason, the more important fauna of the stage eα of Bohemia is described only from the stage eα 3 and this fauna is very similar to the fauna of stage eβ.

The important fauna of the limestone with *Monograptus priodon* (fauna of Kok limestone) exists earlier in the Alps than in Bohemia, for in Bohemia the important limestone fauna first appears in eα 3, but in Sardinia an important fauna of *priodon*-beds is also found. It is therefore impossible that the " Bohemian " fauna has migrated in the upper and middle stages of eα from the Alps into Bohemia. This is a confirmation of the southern character of the Bohemian fauna, which always stands in contrast to the fauna of Gotland and Russia.

The various facies of the Carnic Silurian will now be described. The shales with graptolites have the same appearance as the British ; usually they are black ; the faunas are also similar to those of Britain and Bohemia. In the limestone graptolites are very rare.

The facies of graptolite-shales is not limited to the lower part of the Silurian (Llandovery), as Frech thought. The studies of Gortani have demonstrated that a great part of the Silurian can be represented by shales with graptolites. The faunas of the zones 18–33 (*M. cyphus* to *M. nilssoni*) of Elles and Wood are represented in the Carnic Alps. Most faunas belong to the zones 18–24 (*M. cyphus* to *M. griestonensis*).

I have already mentioned that the lowermost graptolite zones are absent. We see the same feature in Bohemia, in the Harz and in the Wartaer Schiefergebirge (Germany).

Many sections in the Carnic Alps show the shales with graptolites at the base, with the limestones above. For example, in the valley of Uggwa we see graptolite-shales of the zones 19–21 (*M. gregarius* to *M. sedgwicki*) of Elles and Wood, and above them the limestones with Orthocerates.

Other sections show important beds of graptolite shales and only few limestones, e.g. in the valley of Noelbling there are shales with graptolites belonging to the zones 18–33 (*M. cyphus* to *M. nilssoni*).

In other sections the shales with graptolites are absent and he Silurian begins with limestone. The famous section of Cellonetta ear the Plöcken Pass is of this character.

Shales with *Tentaculites* are rare and of no importance.

Two sections will now be discussed in order to show the calcareous acies of the Carnic Silurian in the stages eα and eβ.

The sections of the Kok in the Eastern Carnic Alps is very important on account of the many fossils from the so-called limestone of Kok Kok-Kalk, *priodon*-beds). The fauna of the *priodon*-beds includes :

Monograptus priodon.
Spirigera obovata.

Strophomena comitans.
Spirigera obolina.

Many species of *Lunulicardium* and *Cardiola*, some species of *Slava* (among them also *Slava fibrosa*, which is known from the Upper Llandovery of the Girvan district in Scotland), some species of *Dualina.*

Many gastropods (*Bellerophon*, *Pleurotomaria*, *Murchisonia*, *Lytospira*, *Helcionopsis*, *Platyceras*, etc.)

Many species of *Orthoceras*, of which I cite some :—

Orthoceras transiens.
,, *bacchus.*
,, *striatopunctatum.*
,, *amoenum.*
,, *dulce.*
,, *pauper.*
,, *pleurotomum.*
,, *firmum.*

Orthoceras perlongum.
,, *subannulare.*
,, *potens.*
,, *alticola.*
,, *truncatum.*
,, *acus.*
,, *accuarium.*
,, *currens.*

Many trilobites, of which the most important are the following :—

Ampyx rouaulti.
Bumastus bouchardi.
Cheirurus hawlei.
,, *quenstedti.*

Sphaerexochus mirus.
Encrinurus beaumonti var. *novaki.*
Acidaspis mira.
Cyphaspis burmeisteri.

Arethusina haueri. (This species is very interesting, because Marr[1] has described a very similar form from the zone of *Cyrtograptus murchisoni* in Britain.)

Above the stage eα are the limestone of stage eβ of the Kok.

The second famous section is to be seen at the Cellonetta near the Plöcken Pass. This was studied by Geyer and Gaertner. The sequence of beds is as follows :—

At the base of the section are sandstones and shales of the Carboniferous.

Above them are limestones of Lower Devonian age and then imestones of the uppermost Silurian (eγ). The Carboniferous, the Devonian and the limestone of the stage eγ demonstrate an nversion of beds.

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[1] *Quart. Journ. Geol. Soc.*, lxix, 1913, p. 16.

Above the limestone of stage eγ are Ordovician rocks which are separated from the Silurian (eγ) by a thrust-plane. The Ordovician consists of shales and sandstones of Caradoc age and the Tonflaserkalk of the Ashgillian.

Resting on the Ordovician is a beautiful sequence of Silurian beds with many excellent fossils. This Silurian shows the following divisions :—

1. Dark limestones of the Llandovery, with crinoids and corals. The fauna is not yet studied in detail and therefore it is unknown whether it has a Bohemian character. Its study will yield important information regarding the urgent question of migration of the Alpine fauna into Bohemia. It is possible that the fauna of the Alpine Llandovery is of the British facies. At all events the limestone is equivalent to the stage eα 1 of Bohemia.

2. Above the dark Llandovery limestones, shales with trilobites make their appearance. The trilobites include *Encrinurus beaumonti* Barr. var. *novaki* Frech. They have only a thickness of a few feet, and belong probably to the *priodon*-beds (eα 2). I have found the shales with trilobites at the Rauckkofel and Gaertner has found them at the Cellonetta.

3. Above the shales with trilobites are black and dark red limestones with the fauna of the Kok. They belong to the *priodon*-beds (eα 2). These are the limestones of Kok (Kok-Kalk). Gaertner has proved that the black and dark red limestones of the Cellonetta are of the same age as these Kok limestones.

4. Above the Kok limestone other dark limestones are present. These form the so-called *Cardiola* niveau, for here are beds with many species of *Cardiola* (*Cardiola interrupta*, *persignata*, etc.), and *Monograptus colonus*. Gaertner has found in these beds many of the graptolites of the *nilssoni* zone.

In the *Cardiola* beds are also strata with brachiopods and *Orthoceras*. These include notably :—

Rhynchonella serva.
,, *harpyia.*
Spirigera obovata.
,, *obolina.*
Orthoceras firmum.
,, *amoenum.*
Pentamerus pelagicus.

Also gastropods and trilobites :—

Spirina tubicina.
Cheirurus quenstedti.
Encrinurus beaumonti var. *novaki.*

The stratigraphical position of the *Cardiola*-beds is that of the *dubius*-beds, eα 3.

5. Above the *Cardiola* beds are grey platy limestones and limestones with *Orthoceratidae*, the colour of which is red like a peach-flower. Here is the zone of *Orthoceras alticola* of Frech, while the *priodon* and *Cardiola* beds correspond to the zone of *Orthoceras*

otens of Frech. The platy limestone and the red limestone with *rthoceratidae* belong to the stage eβ.

Comparison with the Bohemian Silurian is effected by means of he subdivisions in the Cellonetta section.

The beds with *Rhynchonella megaera* have an especially important osition. Here are grey limestones with brachiopods and crinoids. *rthoceratidae* and lamellibranchs are of small importance (*Cardiola nterrupta, Cardiola bohemica, Slava bohemica*). The fauna is istinguished by the brachiopods :—

Strophomena ivanonsis.
,, *costata.*
Merista securis.
Retzia umbra.
,, *bohemica.*
Spirigera subcompressa.

Spirigera fugitiva.
,, *obolina.*
Pentamerus pelagicus.
Rhynchonella megaera.
,, *tarda.*
,, *zelia.*
,, *harpyia.*
,, *sappho.*
,, *famula.*

he fauna also contains a good number of gastropods and some trilobites :—

heirurus quenstedti Barr.
Encrinurus beaumonti Barr. var. *novaki* Frech.
rionopeltis striatus Barr.

The study of the fauna shows it to have a position in the higher art of the stage eβ. The comparison with the section of Dlouha hora ear Beraun in Bohemia shows that the beds with *Rhynchonella negaera* occur in the zone of *Monograptus ultimus.*

In Bohemia the highest sediments of Silurian age are called eγ. hey contain an important fauna with many lamellibranchs, some rthocerates, etc. In these beds the last graptolites appear—*Ionograptus hercynicus* and *Monograptus kayseri ; Spirifer inchoans* nd *Hercynella* are also very characteristic of these beds.

The stage eγ of the Carnic Alps is composed of grey, platy mestones with concretions of silica (hornstone) and contains ilicified corals belonging to the genera *Heliolites, Favosites, yathophyllum,* and *Petraia.*

The dark limestones with many gastropods must probably be laced in the upper part of eγ. In these limestones *Hercynella* is ery frequent. We see the same facies as in Bohemia and in the Iarz in Germany. Also the dark limestone with *Hercynella* is ery similar to the limestone of Lochkov (eγ) in Bohemia.

The dark limestones are associated with pale limestones, which lso occur to a great thickness above the dark limestone. The greater art of the pale limestone has yielded many fossils of the stage f Lower Devonian, Limestone of Konjeprus in Bohemia). But that ortion of the pale limestone which is in contact with the dark limestone is older than the Lower Devonian; it is the uppermost Silurian, as is shown by the fossils :—

Pentamerus janus. *Cyrtoceras pugio.*
Spirifer inchoans.

which are very characteristic of the stage eγ.

Finally, I give a table of the divisions of the Silurian of the Carnic Alps and a comparison with Bohemia and with the graptolite zones which Elles and Wood have given in their excellent volume on the British graptolites.

Stratigraphical Palaeontology: an Essay-Review.

By Miss G. L. Elles, D.Sc.

[Stratigraphical Palaeontology; A Manual for Students and Field Geologists. By E. Neaverson, D.Sc., F.G.S., with illustrations of about 500 distinctive fossils. Published by Macmillan and Co. Price 18*s*.]

EVER since William Smith first stated that geological formations might be recognized and separated from each other by their fossil contents, the study of stratigraphy has been intimately connected with palaeontology, but till comparatively recently it has been stratigraphy that has been the gainer, owing gradually more and more to palaeontology as the recognition and development of palaeontological zoning has made classification into subdivisions more possible, and hence chronological successions and accurate correlations of strata in widely separated areas also more possible since based upon more reliable and satisfactory data. Now, however, palaeontology has begun to make definite demands upon stratigraphy; it is realized that different lithological Facies must have a largely controlling effect upon types of faunas, and that any Standard Sequence adopted will be definitely related to a special fauna; also by utilizing the relationships of zonal subdivisions in the field the palaeontologist is endeavouring to make out the true genetic relationships of the different fossils. The locus of the study of fossils is shifting again primarily from the museum or laboratory to the field, and the palaeontologist of to-day should no longer be content to be merely a systematist, but should aim at being also an evolutionist, seeking in the field for the relationship existing between each so-called genus and genus as revealed in continuous succession in time. Stratigraphical palaeontology then in these days may be studied from two points of view, the actual associations and succession of faunas, qua faunas, this, though more elaborated, is essentially the principle of William Smith, and secondly, the more modern aspect which implies the study of the stratigraphical relations of an evolutionary series in limited groups of fossils.

The above book is mainly concerned with the first of these aspects, THE SILURIAN OF CARNIC ALPS: COMPARISON WITH GREAT BRITAIN AND BOHEMIA.

Great Britain.			Carnic Alps.			Bohemia.		
				Dark limestones with flint and corals.	Black limestones with *Hercynella*.	*Mon. hercynicus* and *Mon. kayseri*.		eγ
Lower Ludlow.	Salopian.	36. *Mon. leintwardinensis.*		Red limestones with Orthoceratides and grey platy limestones.	Limestone with *Rhynchonella megaera.*	*Mon. ultimus.*		eβ
		35. *Mon. tumescens.*				*Mon. transgrediens.*		
		34. *Mon. scanicus.*						
		33. *Mon. nilssoni.*	Shales with Graptolites, from the zone 17 (18) to the zone 33.	Limestone with *Cardiola interrupta* and other *Cardiolas.*		*Mon. colonus.*	Dubius-beds.	eα3
		32. *Mon. vulgatus.*						
Wenlock.		31. *Cyrt. lundgreni.*				*Mon. testis.*		
		30. *Cyrt. rigidus.*						
		29. *Cyrt. linnarssoni.*		Black and red limestones with a great fauna of the Priodon-beds (limestone of Kok) shales with trilobites.		*Mon. riccartonensis.*	Priodon-beds.	eα2
		28. *Cyrt. symmetricus.*						
		27. *Mon. riccartonensis.*						
		26. *Cyrt. murchisoni.*				*Cyrt. murchisoni.*		
Gala-Tarannon.	Valentian.	25. *Mon. crenulatus.*				*Mon. spiralis* var. *subconicus.*		
		24. *Mon. griestonensis.*						
		23. *Mon. crispus.*		Dark, argillaceous limestones with corals and crinoids.		*Mon. turriculatus.*	Diplograptus-beds.	eα1
		22. *Mon. turriculatus* and *Rastr. maximus.*				*Rastrites linnaei.*		
Llandovery.		21. *Mon. sedgwicki.*						
		20. *Cephalogr. cometa* and *Mon. convolutus.*				*Rastrites peregrinus.*		
		19. *Mon. gregarius.*						
		18. *Mon. cyphus.*				*Diplogr. vesiculosus.*		
		17. *Mesog. modestus* and *Orthograptus vesiculosus.*						
		16. *Cephalogr. acuminatus.*						

[*To face p. 128.*

and is divided by its author into two parts, one termed “ General Considerations ”, the other “ Faunas of the Geological Systems in Britain ”.

It may be questioned at the outset whether in these days of specialization it is possible for any one author to treat the whole of this vast subject with the same degree of accuracy and completeness, therefore it is not surprising to find that Dr. Neaverson fails somewhat in this respect ; he is so obviously more at home in the second part of the book as a whole, and especially so as one might expect in the section dealing with his own subject.

In the first part of the book, apart from one chapter, he is not so successful, and he fails in the second part to apply principles laid down in the first. This is particularly the case as regards the facts and principles put forward in Chapter IV, which stands out as by far the best chapter in Part I, and one of the best in the book as a whole. There are also in Part I some serious omissions and many statements open to criticism, while all the time the author seems to fight shy of accepting the consequences of evolutional principles, though he fully admits their importance. This tends to produce a feeling of disappointment in reading this part of the book.

It seems a pity in a book bearing the above title, to separate the facts given in Chapter II (Morphology) from those given in Chapter VI (Fossils as indices of horizon). It would be far more striking when dealing with the morphology of the different groups, to have laid emphasis on the features which change progressively in time and are therefore of value in stratigraphy, and then to have followed up at once with an illustration ; thus, for example, in dealing with the features of the supplemental skeleton in Nummulites, it would be more effective at once to show that the different elements come in successively in line, so that the appearance of pillars is a late feature, and taken with the form of the septal filaments, which are successively radiate, meandriform, and reticulate, have afforded Nuttall an opportunity of showing how they may be utilized in the determination of horizons within the Eocene.

There would seem to be some vagueness if not misconception in the author’s mind about several Palaeozoic groups of fossils. In the case of the Graptolites, for instance, it is difficult to understand why all reference to the Dendroidea is omitted, the student being led to suppose that there is only one group of these fossils, and that the Graptoloidea. The sicula in this group should not be described as being prolonged *proximally* but *distally*, and *Dictyonema* is not distinguished by its *habit* from the later Graptoloidea, as the author states, but is a Dendroid and distinguished by its cell characters. Nor is it correct to state that the trends in the Graptoloidea appear in succession “ when the two main trends have reached their maximum ”, but rather, that there is a definite *arresting* of the two earlier trends when the new trend starts, to be resumed when this had reached some way further towards its goal.

Then, too, with so much detail given about corals, it is a pity that there is no reference to Ryder's work, which may cause a modification of the views hitherto held respecting the relation of the Rugosa to other corals. Trends in corals are mentioned, it is true, but the significance of these is missed, and the doctrine of trends is not applied to show how important they may be in stratigraphical work, since they are *successive in time*. Surely, too, in a book of this kind one might expect to find something more than a mere casual reference to the most perfect little study in stratigraphical palaeontology that has yet been given to the geological world, i.e. Carruthers' work on *Zaphrentis delanouei*.

The author seems also to miss the significant points about the Palaeozoic brachiopods, and is inclined to stress too much the value of external characters; how fallacious these may be is common knowledge amongst workers in the Lower Palaeozoic, as has been shown very clearly by Professor Jones in his recent work on *Plectambonites*, so that it is evident that similar external characters may conceal very different internal structures and vice versa; granted that the Lower Palaeozoic brachiopods are in a great state of confusion, there is no reason why attention should not be drawn to such facts as we do know about them, and which have a value in stratigraphy. It is not so much the bare fact of the relative abundance of Orthids in the Ordovician rocks that is important, as the great development of the group that takes place with the acquisition of articulation in the valves, *as is shown by the abundance of Orthids in the Lower Ordovician rocks*. Further, it is the gradual development of the internal skeleton that characterizes the brachiopods of the Silurian (e.g. *Pentamerus* and its allies), together with the rise of the spire-bearing forms, exemplified in *Atrypa* and *Meristina*, though this subgroup attains its maximum development in later formations.

The trilobite section is disappointing, and cannot be regarded as being up to date when no mention is made of the very important work of Raw and Warburg, since the researches of these two palaeontologists must materially affect our whole concept of the classification and natural relationships of this group of fossils.

It is most unfortunate that the author is so afraid of accepting the consequences of evolution in palaeontology, for the future in stratigraphy seems so rich in promise of results based upon evolutional and phylogenetic work, and these will undoubtedly be reflected in the zonal classification of strata upon which he rightly lays considerable stress; but the statement that "the observed facts of evolutional palaeontology form the basis of zonal stratigraphy" is certainly not true at the present day, however much it may be the ideal to be aimed at in the future, so far as is possible and practicable from the point of view of field work; up to the present it has only been very partially carried out, in the Carboniferous rocks Vaughan aimed at it, Carruthers carried it out completely in his classic little work, Bisat also has carried it out partially so far as he has gone, whilst in the Chalk Rowe achieved it; but the original zoning by means of the Graptolites was not of this type, nor has much of the later work involving this group been of this nature, though there has been in some cases an attempt to graft an evolutional plan upon the older zoning. It would have been as well, too, to admit frankly in this connection that the actual term *zone* is used at the present time somewhat indiscriminately, and the recognition of a definite stratigraphical horizon achieved in several ways. Sometimes it is the association of a particular set of fossils constituting a definite assemblage that is characteristic of the horizon, and of these one is chosen as the index and termed the *zone fossil*; at another it is the maximum development in numbers, or the acme of development of a particular fossil from an evolutional point of view, that is the distinctive character; these are small scale divisions; the term zone has also been applied to larger scale divisions such as the Zaphrentis zone or the Dibunophyllum zone of the Avonian; here the term is applied to a general horizon characterized by a concentration of Rugose Corals in the Zaphrentid or Dibunophyllid stage of development, and seems to be comparable with the use of the term *age* as applied to Mesozoic Ammonites; such a term might also be used with advantage to indicate the horizon of concentration of trilobites in the Ctenopygal stage of development in the Lingula Flags, or that of the later Leptoplastus stage of development in the Shineton Shales.

In yet other cases the determination of the horizon is dependent upon the collection of a vast number of specimens and the determination of the average present at different stages of development; such a method is necessary in the case of the freshwater lamellibranchs in the Coal Measures, and seems likely to be of value in determining horizons within the Coal Measures more accurately than can be achieved by the use of plants alone; with yet other organisms, such as the Micrasters, the horizon may be indicated either, by the sum of one character in several specimens, or all the features in one.

Attention should be directed to such things in a book of this kind, as they are clearly important both for the student and field worker.

In dealing with the sudden appearance of abundant forms at some geological horizons, it is probably unnecessary always to invoke migration from a distance, as the author would do; it may well be that the " burst " is due purely to evolution, and marks a notable stage of development, which is particularly successful in the struggle for existence; so for example we have the " burst " of articulate brachiopods at the base of the Ordovician, or the " burst " of Monograpti at the base of the Valentian, that marks the attainment of the uniserial scandent form amongst the Graptolites, the end term of two lines of evolution.

In the second part of the book the author has given us an admirable compilation of the work of the most recent authorities on the subject, and a particularly high level of excellence is reached in the chapters dealing with the Ammonite faunas in the Jurassic; here the most recent work of Spath and Salfeld has been taken into account, and the student is presented with a very clear statement of the present state of our knowledge, and the manner in which it may best be utilized in stratigraphical geology. It is perhaps a little out of proportion to the rest, but it is worth it, as it would probably have been impossible to condense without sacrificing material that makes for clarity, and many students and field workers alike will gladly note the adoption of the grouping into " ages ", such ages being characterized by Ammonites at a certain stage of development which show certain obvious structural features that can be recognized in the field, rather than the minute zonal divisions whose value in field work has yet to be proved. At the same time, it must be noted that the author's frank recognition of the variation in the faunal elements at certain horizons in different areas where lithological conditions change, sounds the note of warning that some of these highly specialized invertebrates may be *conditional* organisms with a very small range of physical stability, a fact which must have a very direct bearing upon the validity of certain supposed non-sequences in stratigraphy.

The illustrations in the book are of varied quality; the idea of having both photographs of actual specimens and line drawings has much to recommend it, but the line drawings should have been more accurately drawn, and should have been taken more carefully from good figures if good specimens were not available. The whole Palaeozoic section of Part II of the book is marred by bad line drawings of both Trilobites and Graptolites, very important elements in the faunas. Particularly bad are the drawings of *Olenellus*, *Holmia*, *Callavia*, and *Ogygia buchi*, whilst it would be hopeless to attempt the recognition of *Mesograptus* or *Pleurograptus* from the illustrations given, for the characteristics are wanting altogether.

Another serious fault is the indiscriminate use or absence of scale; where a scale is only occasionally noted, it is natural to infer that the other figures are drawn to natural scale, which is certainly not so in many cases, on this assumption *Beyrichia complicata* is as large as or larger than *Archaeoniscus brodiei*!

In some cases, too, the figures are badly arranged; it is somewhat strange to find under the heading " Silurian Faunas ", even though labelled " Some Proparian Trilobites ", such forms as *Chasmops macroura* and *Pterygometopus jukesi*, for when some figures are labelled Devonian the natural inference is that the remainder are Silurian, which is certainly not the case; again, too, one does not expect to find *Phillipsinella parabola* and *Cyphaspis megalops* under the heading " Carboniferous Faunas ", even though labelled " Proetid Trilobites ".

Surely the author is mistaken in referring the zone of *D. muirheadi* to D3. There has been a great deal of confusion in the use of this term, but it seems at last to have been shown clearly that the original D2 zone was divided into two, the zone of *Lonsdaleia floriformis* below, and the zone ot *Lonsdaleia duplicata* above, and it is to the last of these that the *D. muirheadi* horizon belongs: it should therefore be Upper D2; only beds above the Orionastraean level are really D3, i.e. the horizon of the Cyathaxonia sub-zone.

It cannot therefore be denied that there are some blemishes in the book, particularly in Part I, and faults as regards some of the illustrations in both parts, but it would not be fair to lay too much stress on these, and it is to be hoped that they will disappear in later editions; there is so much that is really good and that will be found useful to student and field-worker alike, that the book may be cordially recommended to all serious geologists.

G. L. ELLES.

REVIEWS.

INTERIM REPORT ON THE GEOLOGY OF THE CHROMITE DEPOSITS OF THE UMVUKWE RANGE, LOMAGUNDI DISTRICT. By F. E. KEEP. S. Rhodesia Geol. Survey, Short Report, No. 23. 1928.

THIS report is of much petrological interest because it emphasizes as an economic factor, the remarkable synclinal structure as shown by Lightfoot of the Great Dyke of Rhodesia, surely one of the most striking of all known intrusive masses. This dyke is traceable for 330 miles and has an average width of about 4 miles. In the area in question it includes workable deposits of chromite, which are clearly of magmatic origin, forming more or less well-defined bands dipping on either side towards the centre of the dyke: these bands or seams vary from 7 to 30 inches in thickness, and they have at present been followed for about 100 feet down the dip in mining operations. It is estimated that in this area each mile in length of the dyke will produce 200,000 tons of chromite ore down to that depth (presumably meaning that working will take place from both sides).

The author attributes the concentration of the chromite to sinking of crystals during consolidation of the cooling enstatite-magma of the dyke, but it is not quite clear why the sinking crystals should form such well-defined bands along certain horizons: in the sections figured four or five such seams are shown, ranging over depths of several hundred feet, while the author definitely states that in his opinion the dyke is not constituted by a succession of intrusions. An analogy is suggested with the metallurgical process of ore-flotation, but on this point further information is desirable.

THE GEOLOGY OF PILANSBERG (PILAAN'S BERG) IN THE WESTERN TRANSVAAL: A Study of Alkaline Rocks and Ring-Intrusions. By S. J. SHAND. Trans. Geol. Soc. S. Africa, vol. xxxi, 1928, pp. 97–156.

THE area forming the subject of this important paper, usually known as Pilandsberg, is one of the largest known examples of extremely alkaline rocks. It has already been described in considerable detail by Humphrey and by Brouwer, but Dr. Shand has found reason to criticize the work of both these authors, while fully acknowledging its value. The remarkably circular form of this igneous complex naturally invites comparison with certain modern conceptions of ring-dykes and cone-sheets and even with the strange Vredefort intrusion and its possible counterpart in Arran, as expounded by Bailey, but there seems to be little real resemblance, except on a map. Dr. Shand's theory is something like this: after the emplacement of the red granite and norite of the Bushveld there was a residue of granitic magma which reacted with the Transvaal dolomite to form alkaline differentiates; these came up along a series of N.W.–S.E. faults at the point where they intersected the axis of the Bushveld syncline. A group of small volcanoes was first formed, giving rise to a blanket of pyroclastic rocks, and then the syenitic magma formed a laccolith at the base of this accumulation; finally the crown of this laccolith collapsed into the still liquid interior, and masses of nepheline-syenite welled up around it, giving an apparent ring-structure, which does not really extend into the depths, as it appears to do. The sheets of syenite mostly dip towards the centre of the area at fairly low angles, not outwards, as supposed by Humphrey. This excludes the idea of a vast volcanic cone.

This explanation of the geological structure of the Pilandsberg seems to be quite in conformity with recent ideas of intrusion-tectonics. Dr. Shand confesses explicitly in this memoir that he hoped there to find a justification of Professor Daly's hypothesis of the origin of alkaline magmas by assimilation of limestone or dolomite, and was disappointed in this expectation, since no such rocks are exposed anywhere in the Berg, and the syenites contain little or no lime or magnesia: nevertheless it is clear that the magmas must have risen through the thick dolomites of the Transvaal System, and there seems here to be nothing inconsistent with the modified views of the relation of alkaline magmas to calcareous rocks, as recently expounded in an important paper by C. H. Smyth, jun., which provides a reasonable explanation of the common association of such rock-types.

R. H. R.

THE NOMENCLATURE OF PETROLOGY. By ARTHUR HOLMES. Second edition, pp. 284. T. Murby and Co., London, 1928. Price 7*s*. 6*d*.

THE appearance of a second edition of this valuable work is to be welcomed for more than one reason. Firstly it shows the existence of a real interest in the science of petrology, which is liable to be swamped under the prevailing palaeontological bias of geology, at any rate, in this country. Secondly, the reduction in price by no less than five shillings will place the book at the disposal of many to whom it has hitherto been inaccessible. Professor Holmes has been well advised in reducing the necessary alterations to a minimum. A few printer's errors are corrected, and also one or two statements of fact are modified, such as that Trowlesworthy Tor is in Devonshire, and not in Cornwall. As for the introduction of new terms, which is not attempted, there can be no object in perpetuating the latest additions to petrological cacophony, which are bound to be scrapped within the next few years. Although the quality of the paper and the general appearance of the book are not quite up to the previous standard, this is compensated by the reduction in price.

GEOLOGIE AFRIKAS. 2ter Teil. Geologie der Erde. By E. KRENKEL. pp. 463–1000, with 15 plates and 125 text-figures. Berlin: Borntraeger, 1928. Price 48 marks.

THE UNION OF SOUTH AFRICA. By A. W. ROGERS, A. L. HALL, P. WAGNER, and S. H. HAUGHTON. Handbuch der regionalen Geologie. Band vii, 7*a*, pp. 232, with 3 plates and 57 figures. Heidelberg: Carl Winter, 1929. Price 17 marks.

OF late the output of large and authoritative general treatises on the geology of South Africa has been rather overwhelming—Dr. du Toit's splendid volume, the *Geology of South Africa*, appeared in 1926, and was duly reviewed here: the second volume of Dr. E. Krenkel's *Geologie Afrikas*, which is devoted to the same region, is dated 1928, and finally we have the section of the *Handbuch der regionalen Geologie*, entitled "The Union of South Africa", with the date 1929. All this is, of course, peculiarly appropriate in view of the wealth of Congresses and other scientific gatherings with which that land is to be blessed (or otherwise) in the immediate future, but it is a little exhausting to the conscientious reviewer. One can only conjecture what the South African geologists will feel like when the congresses are all over. In order to avoid any appearance of invidious preference the works whose titles are given above will be taken in chronological order.

Perhaps the highest compliment that could be paid to Professor Krenkel's second volume is to say that in many ways it bears a very strong resemblance to Dr. du Toit's book, not only in its scope and contents which is, of course, inevitable, but also in typographical details. A notable difference is the absence of plates of photographs, which were numerous in the first volume of the same work. A rather mysterious remark in the preface indicates that it was intended to have such plates here also, but that something unexplained happened to prevent it. A hint is, however, given that they may accompany the third and concluding volume of the work, which is much to be desired. The northern limit of the area dealt with is lat. 15 degrees south: Rhodesia is therefore included.

As would naturally be expected from a German author, a very full account is given of the geology of South-West Africa, which is in many ways an exceptionally difficult region. One of the outstanding problems of South African geology has always been the correlation of the vast number of different rock masses belonging to the earlier stages of the succession. The base of the Witwatersrand Series, which is here taken as the beginning of the Upper Algonkian, is regarded as a datum-line, but the weak point of this plan is the comparatively small area within which this formation is exposed at the surface. Above this horizon the succession is comparatively plain sailing, in spite of minor difficulties as to the relations of local facies. But in the north-western part of the Cape Province and in South-West Africa there are vast areas of rocks of all kinds whose mutual relations and separation into Lower Algonkian, Archaean, and so forth are still extremely doubtful, owing to discontinuous distribution, change of facies, and the obscuring effect of recent sands over large tracts. In the discussion of the tectonics of the area many terms are introduced for dominant trend lines, such as *Afriziden*, *Kapiden*, and so forth: these read all right in the German, but are very difficult to turn into neat English equivalents. Africide is rather suggestive of insect powder, and Capide is not much better, but it is hard to see how else these terms can be translated. The last-named is used for the fold-ranges of the Cape Province, Cedarbergen, Langebergen, and their continuations, which have been much in evidence in recent discussions of the problem of continental drift. It may be noted that Professor Krenkel ranges himself strongly against the possible continuation of these fold lines into South America, basing his argument largely on the syntaxis of the Somerset East–Cape Hangklip area, which he considers to exclude a westerly continuation of the east-west range. However, it may be noted that the two sets of folds here were not strictly contemporaneous, the Cedarbergen folds having begun to rise rather earlier than the others, and as is set forth in the publication next to be mentioned, there are to be found in this region a series of cross-folds belonging to both series, responsible for the rather confused structure of the area between Worcester and Cape Town; there appears to be no valid reason why the rather later east-west folds should not set in again in full force once this complicated region is overpassed on the west, and the author's argument cannot be regarded as conclusive.

The scope of this work is so great that it is obviously impossible to discuss points in detail, simply from the difficulty of knowing where to begin, or stop. Therefore no attempt will be made to offer a critical examination. A protest may here be entered against the author's unpleasant habit of printing all his stratigraphical successions, even the tables, upside down; that is, with the oldest formation at the top. This is most disconcerting. A pleasing feature is a section of some 11 pages devoted entirely to the history of geological discovery in South Africa, with a very full acknowledgment of the work of the pioneers. The bibliography also is very complete. Some of the Germanized spellings of place-names are rather irritating. The volume is dedicated to the Geological Society of South Africa.

The second item on our list is less wide in scope than the work already referred to, since it is confined to the territories included n the Union of South Africa. It is to be specially welcomed as an exposition by the authorities officially concerned in it of the geology of that great Dominion. Such a work must necessarily be to a large extent a summary of the results obtained by the most competent workers as weighed in the balance by those who have devoted their whole lives to South African geology in all its manifestations. It therefore carries great weight, and may be regarded as the last word on the subject. Since South Africa is one of the few countries in the world where geology is really taken seriously, and not regarded as the amusement of a few rather tiresome cranks, this work should appeal to a wide circle of readers. When we consider in their proper environment the gold of the Rand, the diamonds of Kimberley, the platinum and tin of the Bushveld, the chromite of the Bushveld and of Rhodesia, the coal of Natal, and all the other innumerable mineral products of the country, it can scarcely be denied that the geology of South Africa is one of the most potent forces in the present economic condition of the world.

The first twenty pages, written by Dr. Rogers, give an admirable summary of the morphology and geological history of South Africa: then follow accounts, inevitably somewhat condensed, of the different stratigraphical systems and of the igneous rocks: the main subdivisions are: the Swaziland System, which is here made very comprehensive; the Witwatersrand System; the Ventersdorp System; the Transvaal-Nama System; the Waterberg-Matsap System; the Cape System; the Karroo System; the Cretaceous System; the Cainozoic and later deposits: the Bushveld Igneous Complex and the latest volcanic rocks have sections to themselves. There is also an admirable and remarkably detailed economic section of over 60 pages, quite a large fraction of the book: this is written by Dr. Wagner.

While the book as a whole is worthy of all praise, it is perhaps llowable to take exception to one or two minor points. The bibliographies and references throughout are rather scanty, and very ittle or nothing is said of the work done in the early days by pioneers such as Bain, Stow, Atherstone, Sutherland, and Dunn, before the establishment of official surveys. Finally, referring to matters probably not within the control of the authors, the proof-correcting is very bad, and the painstaking conversion of every measurement mentioned, even the roughest, into its exact metric equivalent is peculiarly exasperating. The author in one place writes " roughly 300 by 200 yards ". This is followed in brackets by " (274·2 by 182·8 m.) ". Further, some of these conversions are incorrect: 16 cubic feet is not 4·53 cbm., and a hundred loads of " blue ground " do not weigh 511·35 grams, which is about a pound and a quarter. Also the paper is unpleasantly thin, and a book priced at 17 marks should not be issued with many loose pages.

R. H. R.

WELLS AND SPRINGS OF SUSSEX. By F. H. EDMUNDS. pp. 263, with 1 plate (map) and 11 figs. 1928. Price 5*s*.

THE author points out that Sussex has some special and peculiar difficulties to contend with in regard to water supply. One is the very fluctuating population of the seaside resorts, and another is the vast consumption of water in car-washing in some of the more plutocratic residential localities. Geologically, also, the county is marked by very great variation in rock-types and consequently in the extent and character of the supplies available. The problems encountered in some of the less-favoured districts are discussed with much lucidity, and the whole work will be of great value to those concerned with the practical side of its subject.

REPORTS AND PROCEEDINGS.

GEOLOGISTS' ASSOCIATION.

7th December, 1928.

" St. Austell Detritals." By J. G. C. Leech.

" Some Features of Cornish Lamprophyres." By H. G. Smith.

Most of the lamprophyres examined lie along a curved strip of country extending from Falmouth, via Newquay, to Wadebridge and Padstow. The rocks contain biotite as the dominant ferromagnesian constituent and are, on the whole, too fine grained for any other mineral to be recognizable in the field. Almost invariably however, occasional inclusions coarser in texture can be found, and the paper is concerned with a detailed examination of these. Corundum, sillimanite, and green spinel are recorded, together with quartz and felspar associated in a manner closely resembling graphic structure.

Some of these patches appear to be fragments of sediments or metamorphic rock in their original condition; others seem to be merely vesicles filled in with low-temperature minerals. If some of the "xenoliths" should prove to be more or less metamorphosed contents of vesicles, it suggests the possibility that the lamprophyres are older than the granites and that the metamorphic aureoles of the latter are more extensive than has been considered.

GLASGOW GEOLOGICAL SOCIETY.

13*th December*, 1928.

"Islay." By Professor J. W. Gregory, D.Sc., F.R.S.

Islay has the attraction to the student of the older rocks of Scotland that all the main groups, Lewisian, Moine, Dalradian, Torridonian, and Cambrian, have been claimed to occur in it.

The pioneer in the area was Macculloch, who regarded the Port Askaig Conglomerate as the representative of the Schichallion Boulder Bed. Murchison and Geikie claimed the Islay Limestone as the Durness Limestone. Thomson, in 1875, classified the rocks of the south-east as Lewisian and the quartzites as Torridon Sandstone. The structure of the island has been very differently interpreted. The Memoir of the Geological Survey, accompanying its accurate maps, appeared in 1907, and it represented the main sequence as ascending from south to north, but complicated by an unconformity, whereby the northern quartzites overlie further south the Islay Slates and Port Ellen Phyllites, and by the Loch Skerrols thrust-plane. Other views have been expressed by Mr. Bailey, Mr. Barrow, and Mr. Green.

Mr. Barrow, who correlated the rocks with those of Perthshire, does not accept the Loch Skerrols thrust and holds that the rocks to the south form a syncline. Mr. Bailey regards the rocks as arranged in an anticline, and holds (probably correctly) that the Islay Slate is not on the same horizon as the Port Ellen Phyllites. Mr. J. F. N. Green also denies the Skerrols thrust and as he discovered in the Bowmore flags the nordmarkite pebbles, the characteristic rock of the Schichallion Boulder Bed, he holds that those flags are of Dalradian age.

The author agrees with the Geological Survey Memoir that the main sequence in Islay is ascending from south to north; but he considers there are two main quartzitic series, the lower or southern being the equivalent of the Jura Quartzite and of the Cammoch Hill Quartzite of Perthshire. This quartzite is thrown by a fault against the northern quartzite and the boulder bed. He regards the rocks as forming an ascending series from south to north and comparable with the succession in Perthshire, the Port Ellen Phyllites being the equivalent of the Ben Lawers Phyllite, the southern quartzite of the Cammoch Hill Quartzite, the Islay Slate and Limestone of the Blair Atholl Series, and the Boulder Bed and overlying quartzite and dolomitic flags of the Schichallion Series (including the Ardnoe Beds).

The Lewisian rocks though not typical are probably correctly thus identified; but of the rocks referred to the Torridonian he agrees with Mr. Green in correlating them as Dalradian as they are earlier than the earth-movements that metamorphosed the Dalradian but not the Torridonian Sandstone; the lower part, highly contorted green schists, may be the equivalent of the Loch Lomond Series.

10*th January*, 1929.

The Metamorphic Rocks of Kintyre. By William J. McCallien, B.Sc., Lecturer in Geology, the University of Glasgow.

The metamorphic rocks of Kintyre belong to the following groups, which are arranged from north-west at the top to south-east at the bottom.

Erins Quartzite: white-weathering quartzite with grits and micaceous bands, and bands of limestone closely resembling the Loch Tay Limestone.

Ben Lui Schists: garnetiferous mica-schists and chlorite-schists in Northern Kintyre. Towards the south garnets are less conspicuous. The group is distinguished by the predominance of micaceous schists. There are some bands of quartzite.

Loch Tay Limestone: coarsely crystalline black marble.

Glen Sluan Schists: schistose grits and chlorite-albite schists.

Green Beds: schists and grits with abundant chloritic and epidotic material.

Beinn Bheula Schists and Grits: a thick series of siliceous schists, grits, and albite-schists.

Skipness Schists: regularly foliated siliceous schists, grits (Carradale Grits and Rudha Leathen Conglomerate), and bands of phyllites.

The Erins Quartzite has not previously been recognized in Kintyre and the Skipness Schists have hitherto been included in the Beinn Bheula group.

The difficult problem of the structure of the above rocks was dealt with in detail. The Cowal Anticline is continued through Kintyre to near Campbeltown, where owing to pitch of the anticlinal axis the rocks bend eastward across the strike of the fold. At Campbeltown the rocks are folded into the Campbeltown syncline, and the rocks of Northern Kintyre are again found in the Mull (of Kintyre) Schists.

North of Campbeltown, where the rocks bend eastward in crossing the axis of the anticline the Loch Tay Limestone advances relatively further to the east than the other groups, and the Green Beds also advance a considerable distance across the underlying schists. The author has, therefore, found it impossible to explain the structures and unusual associates of many of the groups without the use of fold-faults or slides. The main slide over which the Green Beds and Loch Tay Limestone, notably the latter, advance their outcrop across the Beinn Bheula Schists to the Skipness Schists is called the *Lussa Slide*. The *Ranachan Hill Slide* separates Loch Tay Limestone from Beinn Bheula Schists west of Ranachan Hill. In Southern Kintyre, too, there is one important slide, the *Mull Slide* (and many smaller ones), which is responsible for the Loch Tay Limestone cutting across the Green Beds from Cnoc nan Gabhar to Largybaan (a distance of 3 miles).

On the western coast of Southern Kintyre the Mull Schists are folded into three large overturned folds west of Largybaan. These folds have been called the Currach Mor, Dun Ban, and Aignish Folds.

The *Beinn Ghuilean Schists* are similar to the rocks occurring along the eastern coast of Kintyre, to which the name Skipness Schists has been given. South of Campbeltown, therefore, the Kilkerran, Tomaig, and Polliwilline Faults together act as a window whereby Skipness Schists, structurally beneath the Loch Tay Limestone, are brought to the surface with the cover of Loch Tay Limestone and Lussa Slide denuded away.

MINERALOGICAL SOCIETY.

15*th January*.

Professor A. Holmes and Dr. H. F. Harwood: The tholeiite dikes of the north of England.

The suite of tholeiite dikes in the north of England, bounded on the north by the Acklington dike and on the south by the Cleveland dike, form an outlying part of the Mull swarm. To the Salen, Brunton, and Talaidh types already recognized in Mull the authors add Cleveland and Acklington types, and anorthite-bearing varieties of each. Chemical and mineral analyses are presented, and from a comparative study of the evidence it is shown that there are many features in the series as a whole which are not in accordance with the theory of crystallization-differentiation.

Mr. A. Russell: On the occurrence of gold at Hope's Nose, Torquay, Devonshire.

A detailed description is given of a remarkable occurrence of crystallized arborescent gold in calcite, in Middle Devonian limestone at Hope's Nose, where it was discovered by Professor W. T. Gordon in 1922. Specimens, many of which are extremely beautiful, have since been obtained from five distinct veins. The gold varies in colour from a bright rich gold to almost silver-white, and has a silver content of only 1·89 to 8·41 per cent.

Mr. H. E. Buckley: Crystallography of some organic compounds.

Collected records of goniometric measurements on crystals of various organic compounds.

OBITUARY.

Sir William Boyd Dawkins.

William Boyd Dawkins was born at Buttington, Welshpool, on 26th December, 1837 ; therefore at the time of his death he was in his 92nd year. He was educated at Rossall, and at Jesus College, Oxford, where he took a second class in classics and a first class in natural science and was the first holder of the Burdett-Coutts scholarship. He joined the Geological Survey in 1861, where he remained till 1869. In 1870 he became lecturer in geology at Owen's College, Manchester, and Professor in 1872, having been elected a Fellow of the Royal Society in 1867. At one time of his life he travelled a great deal and delivered the Lowell lectures at Boston in 1880. In 1882 he was elected an honorary Fellow of his college, and received the honour of knighthood in 1919.

His attention was early directed to the borderland between geology and history, in connection with which his early classical training stood him in good stead. He made a special study of the mammalia of late geological times, and was naturally attracted by the problems connected with Early Man. As much evidence was then being obtained from caves he began a careful exploration of some of them, studying their physical characteristics as well as their organic contents. While doing this work he was often led into positions of difficulty and even danger, for he was an intrepid explorer. The evidence obtained from the caves was summarized in his well known work, *Cave Hunting*, published in 1874. Another work, *Early Man in Britain*, appeared in 1880: in this the whole question of Prehistoric Man was reviewed, and his own contributions to it summarized.

About this time Dawkins appears to have been confronted with the question as to whether he should devote himself chiefly to pure or to applied geology. He chose the latter and his geological confrères have deplored the decision. It is possible, however, that his choice was a wise one, for his versatility was such that he might have rebelled against too specialized a calling. As it is, he did much of value in various ways: his work for the city of Manchester was specially noteworthy, but these activities do not affect the geologist and need not be recorded here. As regards economic work his name is chiefly associated with the Channel Tunnel and the Kent Coalfield, but he did an enormous amount of work in connection with geological problems of all kinds, and never entirely abandoned pure geology. Late in life he returned once more to his early love, Pleistocene and Prehistoric animals, and was actually engaged within a few months of his death in studying the Prehistoric Mammalia of the East Anglian Fenland.

He had a sunny nature and a delightful personality, and had endeared himself to a large circle of acquaintances in all ranks of life.

Professor E. H. L. Schwarz.

Ernest Hubert Lewis Schwarz was born in London and educated at Westminster. He went out to South Africa about 1895 and spent a year at Johannesburg as editor of the *Scientific African*. In 1896 he began a period of service on the Geological Commission of the Cape of Good Hope on its formation under Dr. A. W. Rogers. This lasted ten years, and was productive of a large amount of very useful work, especially on the geology of the Cape System and older rocks in the southern and western parts of Cape Colony, as well as important contributions to the elucidation of the Cretaceous and Tertiary of the eastern part of the same colony. In 1905 Schwarz was appointed to the chair of geology at the Rhodes University College, Grahamstown, a post which he continued to hold till the time of his death. He published two small books; one a most useful summary of South African geology, the other entitled *Causal Geology*, which contained much bold and probably unfounded speculation. His later years were largely occupied by a great scheme for reclaiming part of the Kalahari region and increasing the rainfall of South Africa generally by diverting southwards some of the head-waters of the Zambesi, which he believed to have originally run in that direction, but to have undergone capture.

Schwarz was a man of much originality, and some of his ideas, though geologically very unorthodox, were at least stimulating.

CORRESPONDENCE.

PSEUDOTACHYLYTE.

SIR,—It is well established that glassy films and veins of pseudotachylyte and "flinty crush rock" are not igneous intrusions, but result from the mechanical shearing of solid rock, and that the liquid thus produced may be injected away from its source of origin (see Clough, Maufe, and Bailey, *Q.J.G.S.*, 1909, pp. 611–78, and Shand, *Q.J.G.S.*, 1927, pp. 198–221). The conclusion has been drawn that at the surfaces of movement the temperature has been raised sufficiently to melt the rock. The main difficulty lies in the unlikelihood of the generation by friction of enough heat to fuse minerals like quartz and felspar, and this finds support in that the effects of high temperature are conspicuously wanting in the majority of those occurrences which have been described—the pseudotachylytes exhibit devitrification rather than normal crystallization.

A clue to the origin of these puzzling rocks may perhaps be found in the work of the late Sir George Beilby (*Aggregation and Flow of Solids*, Macmillan, 1921). Beilby associates the properties of "cold-worked" metals with the production at the planes of movement of a vitreous modification—i.e. liquefaction may be induced by shearing stress at temperatures far below the normal fusion point. Some significant experiments were made on minerals in illustration of this. It was demonstrated that when calcite is lightly stroked with chamois leather a film of calcium carbonate glass is formed, and even a quartz surface may be liquefied at ordinary temperatures by rouge polishing. Beilby concludes that in solid flow a glass results wherever differential movement occurs.

Thus the production of rock glass in zones of severe shearing at temperatures far below the fusion points of the vitrified minerals is to be expected, and the descriptions given of many occurrences of pseudotachylyte are in harmony with this mode of origin. With regard to the dispersion of the glass from its place of origin, it may be noted that under pressure glass will flow at temperatures well below the fusion points of the common rock-forming minerals, and a moderate increase of temperature due either to the friction or to a regional rise in temperature would make injection possible.

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ANNOUNCEMENTS AND INQUIRIES.

PEACH AND HORNE MEMORIAL.—A project to perpetuate the memory of the late Drs. Peach and Horne has recently been inaugurated in Edinburgh. Benjamin Neeve Peach, LL.D., F.R.S., died in January, 1926, and his life-long friend and fellow-worker, John Horne, LL.D., F.R.S., followed him in May, 1928. In response to a widely expressed desire that the eminent services rendered to geology by these two distinguished scientists should be recognized in some appropriate form, a representative meeting was convened and has now decided to take steps to raise a joint memorial. The committee includes delegates from the Geological Survey of Great Britain, the Royal Scottish Museum, the Geological Departments of the Scottish Universities, and the following scientific societies with which Drs. Peach and Horne were most closely identified: Royal Society of Edinburgh, Royal Scottish Geographical Society, Royal Physical Society of Edinburgh, and the Geological Societies of Edinburgh and of Glasgow.

The committee proposes, with the concurrence of the authorities concerned, that the memorial take the form of a bronze plaque to be placed in a suitable position in the Royal Scottish Museum, Edinburgh, and of a commemorative inscription upon some conspicuous rock-face or boulder at one of the classical geological localities in the North-West Highlands. A fund has been opened to defray expenses and the committee has appointed Mr. M. Macgregor, Southpark, 19 Grange Terrace, Edinburgh, to receive and acknowledge all contributions.